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Advances on polysaccharides from cactus: analysis and review based on bibliometrics

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Abstract. Plant polysaccharides are beneficial for developing new drugs, nutraceuticals and functional foods. Cactus is of interest to researchers in agronomy, medicine and food chemistry because of its long history of medicinal use, its simple growing requirements and biological basis for becoming a green vegetable. This review provides the first summary and analysis of the research history of cactus polysaccharides through a bibliometric approach. Bibliometrics was used to investigate the focus of different stages of development of the topic, with contributions from different countries and institutions. In addition, keyword analysis and keyword clustering were used to understand the different research directions of this topic. The analysis showed that: (1) considerable work on plant polysaccharides in the Cactaceae family has focused on *Opuntia spp.* (2) The study of cactus plant polysaccharides is a long-established topic but did not attract much attention in its early stages. (2) In 2018, research on cactus polysaccharides has received more attention than ever before. (3) Mexican institutions and scholars constituted the most important contributions to this topic. (4) This theme has only formed one complex network of cooperation, mainly composed of Mexican institutions and scholars. (5) Early studies on cactus polysaccharides focused on the detection, extraction and purification of polysaccharide content. (6) The biological activities of plant polysaccharides have gradually become the focus of research in recent years. (7) The biological activity of plant polysaccharides has been verified from *in vitro* and *in vivo* experiments with positive results.

Keywords: *Opuntia spp.; Statistical analysis; CiteSpace; Extraction; Biological activity*

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Introduction

Plant carbohydrates account for more than 80% of the dry matter and include monosaccharides, disaccharides, oligosaccharides and polysaccharides. Plant polysaccharide is a polysaccharide produced by plant cell metabolism (Warnakulasuriya *et al.,* 2018). Generally, plant polysaccharides are composed of hundreds of monosaccharides, and their properties differ from those of monosaccharides. Plant polysaccharides are widely used in food, pharmaceutical and daily chemical fields and have become a hot spot in food science, natural medicine and life science (Shao *et al.,* 2020). Numerous studies have shown that plant polysaccharides have biological activities such as immunomodulation, antioxidant, anti-fatigue, hypoglycemic, hypolipidemic, anti-tumour, anti-radiation, anti-bacterial, anti-virus, and liver protection (Li *et al.,* 2018). Several hundred polysaccharides have been isolated from natural products, among which water soluble polysaccharides extracted from plants have been studied most extensively. Cactus is the common name of the species belong to family Cactaceae, comprising about 127 genera with 1750 known species. Cactus is native to tropical and subtropical arid regions of North and South America and is now found in temperate regions of the world, especially in Mexico, where it is most abundant and commonly cultivated as a nutritious food (Delgado-Ramírez *et al.,* 2021; Mitchell, 2021; Pensamiento-Niño *et al.,* 2021; Matus *et al.,* 2022).

Cactus contains energy substances such as fats, proteins and carbohydrates, as well as active ingredients such as alkaloids, polysaccharides and flavonoids (Bouaouine *et al.,* 2018; Hailu, 2020; Sigwela *et al.,* 2021). Polysaccharides are currently recognized as the main active component in cactus and have also become a hot topic of research on cactus in recent years. The composition and structure of cactus polysaccharides are complex, and many researchers have extracted and isolated different polysaccharides from different species and genera of cactus. Cactus polysaccharides contain homopolysaccharides, heteropolysaccharides and glycoproteins with different polysaccharide contents, relative molecular masses and monosaccharide composition ratios (Huang *et al.,* 2009; Riaz *et al.,* 2021). Cactus polysaccharide extraction methods mainly include the hot water method, acid method, enzyme method, ultrasonic method, microwave-assisted method, microbial method, etc. The extracted crude polysaccharide of cactus often contains protein, pigment, small molecules, and other impurities that need to be removed (Cai *et al.,* 2008; de Andrade Vieira *et al.,* 2021).

So far, several reviews have described the progress of research on cactus components (Goycoolea *et al.,* 2003; Stintzing *et al.,* 2005; Moßhammer *et al.,* 2006; Shedbalkar *et al.,* 2010; Shetty *et al.,* 2012). Some other reviews on plant polysaccharides include cactus polysaccharides (Xie *et al.,* 2016; Yuan *et al.,* 2021; Felicia *et al.,* 2022). However, the research advances in these reviews on cactus polysaccharides' extraction, purification, structural characterization and bioactivity need to be updated. In addition, this series of reviews used traditional methods for interpreting the highlighted literature. The development of bibliometrics in recent years has allowed for a more statistically dependent presentation of the reviews. Bibliometric analysis is a literature and information mining method based on mathematical statistics. It can reflect research trends and hotspots through clustering relationships of keywords in the literature and has become an important tool for global analysis in various scientific fields (Fu *et al.,* 2022; Jin *et al.,* 2022; Li *et al.,* 2022; Shen *et al.,* 2022; Zheng *et al.,* 2022 a; b; c). This review summarizes the research progress of polysaccharides from the cactus.

Material and Methods

Two bibliometrics software have been used in this systematic literature review. The first is CiteSpace, developed by Dr. Chaomei Chen, a professor at the Drexel University School of Information Science and Technology (Börner *et al.,* 2003; Chen, 2004, 2006; Chen *et al.,* 2010). CiteSpace 6.1R2 was used to calculate and analyze all documents. COOC is another emerging bibliometrics software (Xueshu *et al.,* 2022). COOC12.6 was used to analysis of annual publications. We used the core collection on Web of Science as a database to assure the integrity and academic quality of the studied material. "cactus polysaccharide", have been used as a "Topic." The retrieval period was indefinite, and the date of retrieval was July 30, 2022. 112 articles were retrieved, spanning the years 1991 to 2021.

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Results

Literature Development Trends

The paper on polysaccharides from cactus in the core collection on Web of Science dates back to 1991. Nerd and Nobel (Nerd *et al.,* 1991) analyzed the composition of *Opuntia ficus-indica* (L.) Miller under well-watered and drought-stricken conditions for 15 weeks. The analysis of polysaccharides is one of the indicators. They found an increase of polysaccharides (probably starch) in the water-storage thin-walled tissue of *Opuntia ficus-indica* (L.) under drought conditions. The composition in *Cerus peruvianus* was investigated by Alvarez et al. (Alvarez *et al.,* 1992) in 1992. They found that the main component of gum fraction was an uronylated rhamnoarabinogalactan with a viscosity that may exceed 1000 mL g^{-1}. This composition was precipitated and washed by ethanol to obtain an almost protein-free soluble mucopolysaccharide that can be used as a flocculant for water impurities and as an adjuvant in cosmetic formulations. Figure 1 shows the annual and cumulative number of publications related to cactus polysaccharides. Although this topic has received attention as early as 1991 (this does not mean that the topic has only been investigated since 1991, as the papers used here only consider the core collection on Web of Science), not every year has been published. Since 2002, this topic has entered a stable phase, with papers published yearly. Until 2017, this topic did not show significant growth, and only some of these years had more annual publications, such as 2008, 2012 and 2016. Starting from 2017, this topic entered a period of significant growth. More than 5 articles were published each year, reaching a peak of 12 articles in 2019. While the number of papers published worldwide has increased significantly over the past five years, an increase in annual publications on a topic still means it is starting to attract more people to it. Although the survey of cactus plant polysaccharides can be published in a range of non-English speaking indigenous academic journals due to the geographical distribution of cactus, the increase in the number of papers on this topic in the core collection on the Web of Science database reflects that it is gaining more popularity among international scholars.

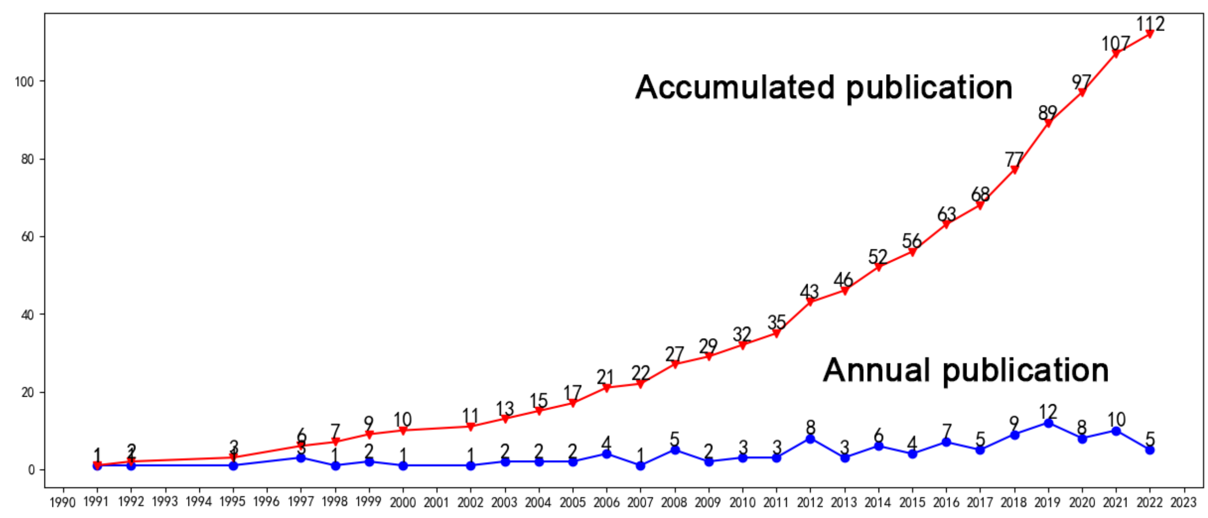

Figure 1. Annual and accumulated publications from 1991 to 2022 searched in the Web of Science about polysaccharides from cactus.

Journals, Cited Journals and Research Subjects

Figure 2 shows a tree diagram of the top 6 journals publishing the number of polysaccharides from the cactus. Polysaccharides are carbohydrates; therefore, Carbohydrate Polymers has published the most significant number of papers on this topic. The papers in this journal focus on the investigation of the properties of cactus polysaccharides. For example, Manhivi et al. (Manhivi *et al.,* 2018) investigated the composition, rheology and thermal properties of *Opuntia spp.* mucilage. The Journal of the Professional Association for Cactus Development publishes scientific articles about the Cactaceaes and near-family species communities worldwide. Therefore, it has also made a remarkable contribution to this topic. For example, Armenta *et al.* (2009) investigated the structure of polysaccharides in *Opuntia matudae* fruits of different ripening stages. Cardenas *et al.* (1997) investigated the rheological behaviour of polysaccharides isolated from *Opuntia ficus-indica*. The journals in Figure 2 are all in the food field except for one botanically related. Because cactus mucilage has potential applications in many fields. Therefore, a series of works focused on mucilage extraction, purification and compositional analysis. For example, De Andrade Vieira *et al.* (2021) recently published a study on the physicochemical properties, structure and technological properties of the mucus extracted from seven cladodes of cacti (*Opuntia fícus-indica*, *Opuntia cochenillifera*, *Cereus jamacaru*, *Cereus hildmannianus*, *Pilosocereus gounellei*, *Tacinga inamoena* and *Pilosocereus pachycladus*) and found that arabinose is the main polysaccharide.

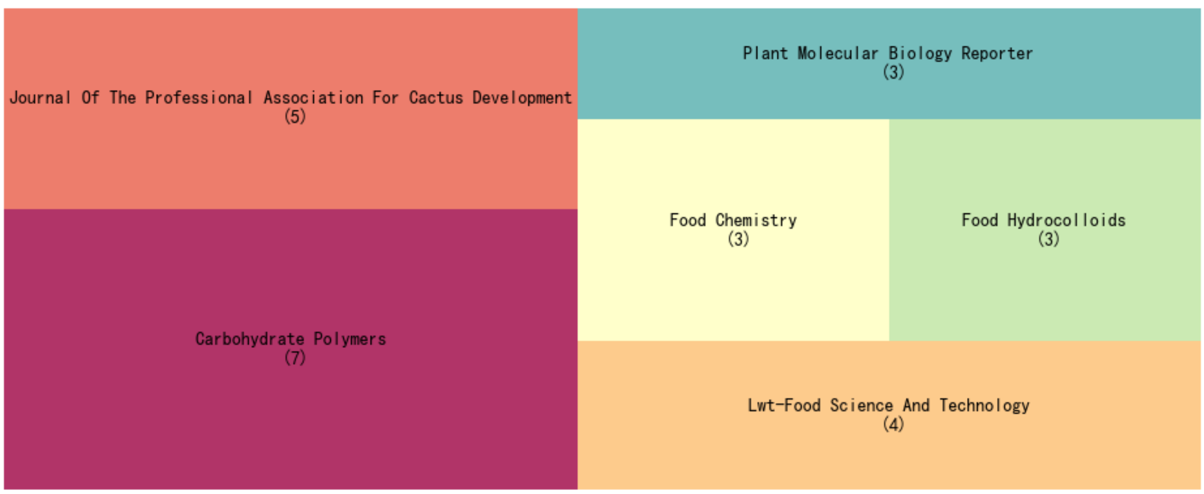

Figure 2. Top 6 journals that published articles on the polysaccharides from cactus.

In addition to the number of papers published by the journal on the topic, the frequency with which the journal is cited by papers related to the topic is also an important indicator. Table 1 shows the top 12 cited journals on the polysaccharides from the cactus. The table shows that Carbohydrate Polymers continue to rank first and are the most frequently cited journal. This represents not only a large number of papers on polysaccharides from cactus published in this journal, but the academic community has also recognized these papers. However, the rankings in Table 1 are not entirely objective, as whether a paper is widely cited receives influence from academic publishers. Therefore, we counted all journals with more than 20 citations in Table 1, representing that they all have an important contribution to the development of this topic. Most of the journals in Figure 2 appear in Table 1, except for Lwt-Food Science and Technology and Plant Molecular Biology Reporter. This means that the papers on polysaccharides from cactus published in these two journals have not attracted much attention. In addition, some additional information is given in Table 1. For example, journals related to phytochemistry and analytical chemistry are included in Table 1. This represents polysaccharides from the cactus involved in the analysis of phytoconstituents. The appearance of Journal of Arid Environments also makes sense since the cactus is a very important group of plants in arid ecosystems.

Table 1. Top 12 cited journals on the polysaccharides from cactus.

No.	Citation	Cited Journal
1	63	Carbohydrate Polymers
2	47	Food Chemistry
3	40	Journal of Agricultural and Food Chemistry
4	35	Carbohydrate Research
5	31	Journal of the Professional Association for Cactus Development
6	29	Journal of Arid Environments
7	26	International Journal of Biological Macromolecules
8	26	Food Hydrocolloids
9	25	Phytochemistry
10	23	Analytical Biochemistry
11	22	Journal of Food Science
12	21	Food Research International

To further explore the information that journals provide, we constructed a co-occurrence network of cited journals related to polysaccharides from the cactus (Figure 3). Journals highlighted in Figure 2 and Table 1 are not labelled. Analytical Biochemistry, ranked #10 in Table 2, has a very strong betweenness centrality in Figure 3, representing that the content of this journal connects two different fields. Another journal of analytical chemistry, Analytical Chemistry, plays a similar role. After interpreting the journals connected around them, the information related to cactus polysaccharides in these journals is about the extraction, isolation and analysis of plant components. Another cluster is included in the lower part of Figure 3, where the journal with the strongest intermediary centrality is Journal of Arid Environments. In addition, Acta Horticulturae is also an important journal in this cluster. They link ecology and a range of food-related journals. In the upper left corner of the entire network is another journal with high intermediary centrality, Annals of the New York Academy of Sciences. It links to journals related to the analysis of cactus phytoconstituents and the exploration of molecular mechanisms (e.g. Cell Biology International, Journal of Clinical Neuroscience, Cellular and Molecular Neurobiology, etc.).

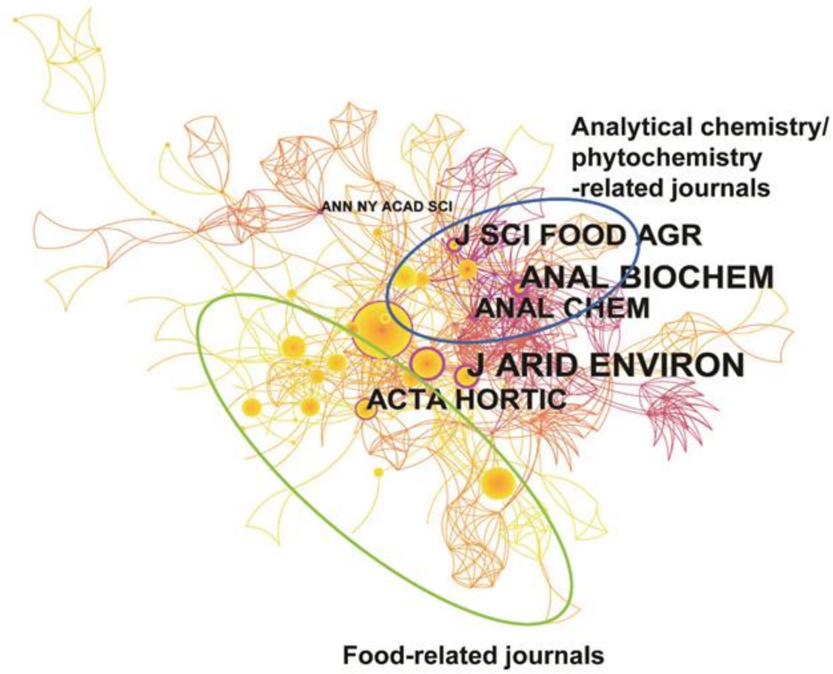

Figure 3. Co-occurrence network of cited journals for polysaccharides from cactus.

Table 2 shows which cited journals this theme was extended to for the first time between 2020-2022. Analyzing journals that have published papers related to a topic for the first time in recent years provides an insight into the most current developments. As shown in Table 2, the journals that published papers on cactus polysaccharides for the first time in the last three years were still mainly concentrated in food, biological and comprehensive journals. However, it is worth noting that materials science-related journals, especially polymer-related journals, appear in 2020 and 2022. Shanmugavel *et al.* (2020) tried the incorporation of bio-additives prepared from cactus extracts into cement concrete mixtures and tested the fresh and hardened state of the modified concrete. In addition, there are the first publications on this topic in water treatment/water environment-related journals in 2021 and 2022. Hussain and Haydar (Hussain *et al.,* 2021) prepared a novel plant flocculant using *Opuntia stricta* (Adjeroud *et al.,* 2015, 2018; Djerroud *et al.,* 2018; Adjeroud-Abdellatif *et al.,* 2020). The results showed that the main component in the flocculant was polysaccharide. Asnam *et al.* (2022) prepared porous composites from the cactus extract and sodium alginate and tested the potential of this material to replace PVA as an adsorbent gel.

Table 2. List of journals has appeared in the co-occurrence network in the last three years.

Year	Journal
2022	Biomolecules; Journal of Water Process Engineering; Natural Product Research; Polymer Bulletin
2021	Clean-Soil Air Water; Journal of The Serbian Chemical Society; Phyton-International Journal of Experimental Botany
2020	Agrociencia; Construction and Building Materials; International Journal of Dairy Technology; International Journal of Polymer Analysis and Characterization; Journal of Food Quality; Metabolites; Polymers; Scientific Reports

The category of the published paper can reflect the evolution of the topic. Figure 4 shows the evolution of the category of polysaccharides from the cactus over time. The topic began in Plant Sciences and covered a range of plant and biology-related areas through 2000. It is noteworthy that this topic had already started to venture into the field of material science in this period. There are two possible interpretations here. As mentioned before, the cactus extract may be used as a green additive to prepare new types of concrete. Another possibility is that the cactus extract was used as a raw material for a green preservative for metal preservation. The preparation of green preservatives from plant extracts is a subject that has a long history and has been attracting the attention of materials scientists (Alrefaee *et al.,* 2021). Since 2003, cactus polysaccharides have entered another important field, Food Science & Technology. After that, this topic started to be cross-researched with chemistry and pharmacology. At the same time, the application of cactus polysaccharides began to be investigated, so some papers were published in journals related to Immunology, Neurosciences, Cell Bilogy. In 2018, the application of cactus polysaccharides was extended to Water Resources. In recent years, this topic started to enter some completely different fields than before, such as Physics (Civil), Energy & Fuels, Materials Science (Coatings & Films).

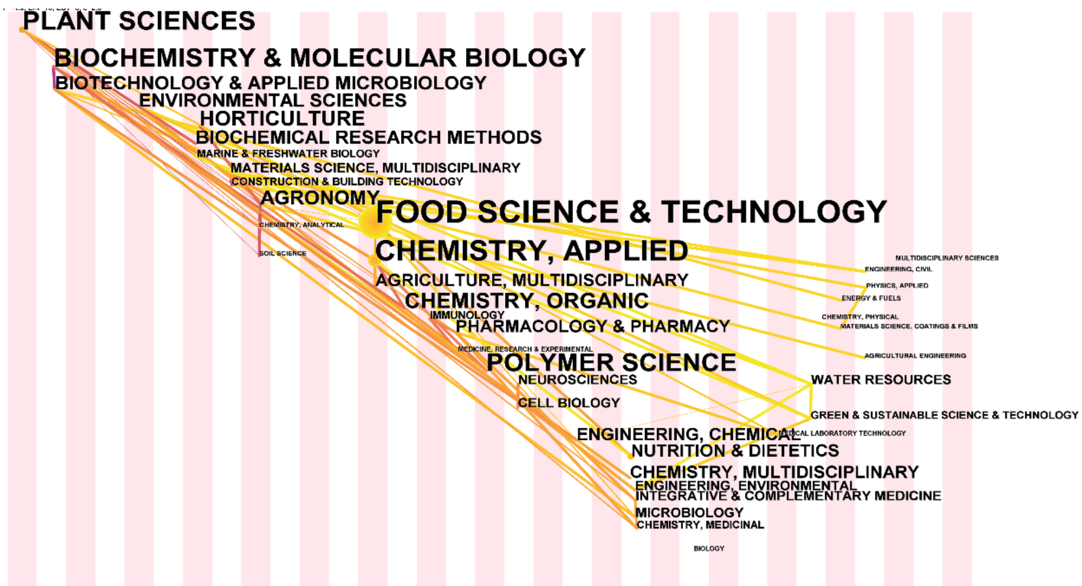

Figure 4. Time-zone view of research categories for polysaccharides from cactus.

Geographic Distribution

Figure 5 shows the pie chart of papers related to polysaccharides from cactus contributed by different countries. Mexico significantly contributed to this topic, contributing 18.1% of the papers. Both China and USA contributed >7% of the papers. France and Brazil contributed >5% of the papers. As seen in Figure 5, although the growth of the cactus is geographically limited, the investigation of its polysaccharides has not been restricted to a few countries. On the contrary, scholars from all geographical regions have demonstrated interest in this topic. As of 2022, a total of 46 countries are investigating this topic, with U.A.E, Poland and Romania being the first to publish on this topic after 2020.

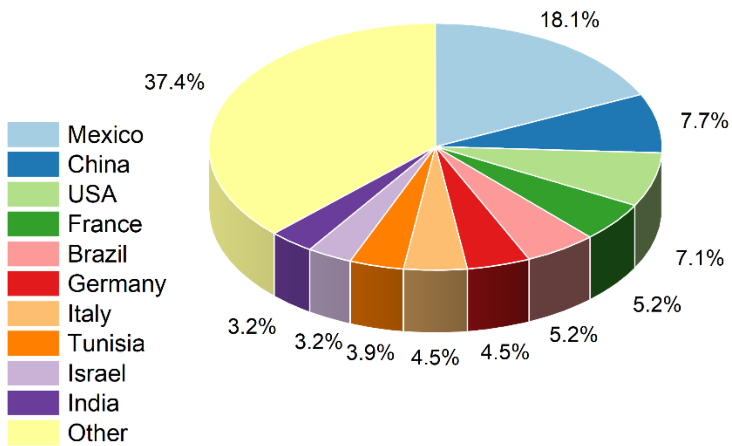

Figure 5. Pie chart of papers related to polysaccharides from cactus contributed by different countries.

Figure 6 illustrates the cooperation network between the different institutions on this topic. Although the topic has attracted the participation of different countries around the globe, only one network of cooperation has been formed. This collaborative network occupies a very important place in this topic. This collaborative network includes a series of Mexican universities and research institutions, mainly led by Colegio de Postgraduados, Universidad Autónoma del Estado de Hidalgo, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Universidad Autónoma de Sinaloa. In addition to this significant collaborative network, only a scattering of other institutions has taken to the collaborative investigation of this topic. It is worth noting that these collaborations are limited to domestic cooperation rather than international cooperation. This may be due to differences in the distribution and introduction of cacti in different countries. On the other hand, this topic may not have a challenge that needs to be urgently tackled, so different researchers focus on different perspectives.

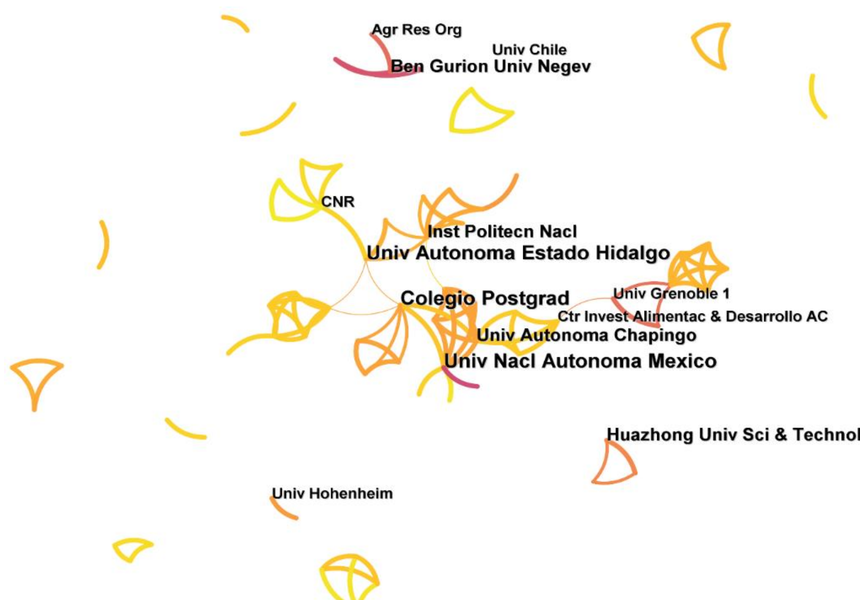

Figure 6. Institution cooperation network for polysaccharides from cactus.

Keyword Analysis and Evolution of The Field

The most effective way to understand the direction of investigating concerns in a topic is the analysis of keywords. Table 3 lists the top 17 keywords in this topic. Not surprisingly, Polysaccharide was the most frequently occurring keyword in this theme. The second most frequent keyword was *Opuntia ficus-indica*, representing it as the most popular specie among the many cacti. *Opuntia ficus-indica* is a species of cactus that has long been a domesticated crop plant grown in agricultural economies throughout arid and semiarid parts of the world. It has assumed the role of "model plant" in a series of scholarly studies on cacti. Research on plant polysaccharides cannot be done without extraction techniques. Appropriate extraction techniques are necessary to obtain extracts containing as many polysaccharides as possible. The high purity of plant polysaccharides can be obtained by separating the extracts. Therefore, extraction is also a keyword that appears frequently. In the extraction of cactus, besides polysaccharides, other substances such as Mucilage, Dietary fibre and Pectin have also received attention (Cárdenas *et al.,* 2008; Lira-Ortiz *et al.,* 2014; Gheribi *et al.,* 2018). The plant organs of the cactus used to extract polysaccharides were also investigated. Table 3 shows that Cactus pear fruit (Montoya-Arroyo *et al.,* 2014; Robert *et al.,* 2015) and Cladode (Petera *et al.,* 2015) were the most frequently investigated organs. When the properties of cactus polysaccharides are investigated, the antioxidant properties are the ones that are most often focused on.

Table 3. List of top 17 keywords for polysaccharides from cactus.

No.	Freq	Centrality	Keywords
1	48	0.29	Polysaccharide
2	40	0.15	*Opuntia ficus-indica*
3	19	0.23	Extraction
4	17	0.33	Antioxidant activity
5	15	0.13	Cactus pear
6	13	0.13	Mucilage
7	12	0.09	Fruit
8	8	0.08	Dietary fiber
9	7	0.19	Acid
10	6	0.28	Cactus
11	6	0.13	Cladode
12	5	0.06	Chemical characterization
13	5	0.18	Extract
14	5	0.14	Film
15	5	0.00	Optimization

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16	5	0.03	Food
17	5	0.17	Pectin

Cluster analysis can further understand the different directions of investigation in this topic. Figure 7 shows that 9 clusters were formed after clustering the keywords. Some of these clusters have overlapping sections, representing a strong similarity between the papers. However, it is also possible to see that some of these clusters are more independent from others, representing that they focus on a specific topic. From the clustering results, the study of polysaccharides from cactus has shown different directions in the course of history. This situation is generally because the investigation of a topic has undergone different stages. After a series of problems have been overcome or investigated, a topic begins to move into a deeper investigation. Table 4 describes the clusters and their ID, size (number of papers), silhouette, and respective keywords. The following is a short explanation of each cluster:

Table 4. Knowledge clusters in the topic polysaccharides from cactus on keyword co-occurrences for each cluster.

Cluster ID	Size	Silhouette	Keywords	References
0	44	0.929	Polysaccharide; Apoptosis; Extract; Aloe vera; Nitric oxide;	(Huang *et al.,* 2008 a, 2009; Chen *et al.,* 2011, 2021; Deters *et al.,* 2012; Ejaz *et al.,* 2014; Li *et al.,* 2014; Ben Saad *et al.,* 2017; da Silva Brito *et al.,* 2020; Otálora *et al.,* 2021; Zhang *et al.,* 2022)
1	33	0.877	Cactus pear; Chemical characterization; Color; Betalain; Quality	(Mattagajasingh *et al.,* 2006; Moßhammer *et al.,* 2006; Luna-Paez *et al.,* 2007; Ramírez-Truque *et al.,* 2011; Di Cagno *et al.,* 2016; Giglio *et al.,* 2020)
2	30	0.879	Extraction; Acid; Optimization; Aroma; Rheological property; Cellulose	(Ninio *et al.,* 2003 a; Cárdenas *et al.,* 2008; Felkai-Haddache *et al.,* 2016; López-Mercado *et al.,* 2018; Camelo Caballero *et al.,* 2019; Silva *et al.,* 2019; Nagarajan *et al.,* 2020; Santagata *et al.,* 2022)
3	25	0.945	Fruit; Behavior	(Fox *et al.,* 2012; Nharingo *et al.,* 2015; Madera-Santana *et al.,* 2018; Asnam *et al.,* 2022)
4	24	0.872	Dietary fiber; Chemical composition; Bioactive compound; Functional property	(Armenta *et al.,* 2009; Nuñez-López *et al.,* 2013; de Campo *et al.,* 2018; El-Shahat *et al.,* 2019)
5	24	0.979	Antioxidant activity; Stroke; Polyphenol; Brain slice; Food; Biological activity	(Huang *et al.,* 2008 b; a; Kim *et al.,* 2013, 2014; Xie *et al.*, 2016)
6	23	0.896	Ficus indica; Mucilage; C13 NMR; Water relation	(Nobel *et al.,* 1995; Mondragon-Jacobo *et al.*, 2000; Vignon *et al.,* 2004; Ramírez-Truque *et al.,* 2011; Lira-Ortiz *et al.,* 2014; Montoya-Arroyo *et al.,* 2014; Rivera-Corona *et al.,* 2014; Manhivi *et al.,* 2018;

				Raimundo *et al.,* 2018; Hussain *et al.,* 2021; Makhloufi *et al.,* 2022)
7	22	0.964	Cactus; Cladode; Cactaceae; Plant	(Nerd et al., 1991; Nobel *et al.,* 1995; Peña-Valdivia *et al.,* 2012; Ciriminna *et al.,* 2019)
8	16	0.905	Prickly pear; Component; Constituent	(Ninio *et al.,* 2003 b; Habibi *et al.,* 2004)

0 (Polysaccharide) The papers on this topic contain many papers focusing on the determination of a range of properties of cactus extracts and polysaccharides. For example, Huang *et al.* (2009) determined cactus polysaccharides' neuroprotective and antioxidant effects *in vivo* and *in vitro*. Rats were used in this work for the study. The study found that cactus polysaccharides reduced neurological deficit scores after cerebral ischemia-reperfusion. It reduces cerebral infarct volume and cortical neuronal loss by decreasing inducible nitric oxide synthase protein synthesis. Saad *et al.* (2017) discovered the protective effect of lithium cactus polysaccharide-induced liver injury in rats. Li *et al.* (2014) investigated the antitumor effect of cactus polysaccharides on lung squamous carcinoma cells SK-MES-1.

1 (Cactus pear) The study of cactus pear is often separated from the study of cladode. This cluster contains a series of papers investigating cactus pear. Ramírez-Truque *et al.* (2011)investigated the composition of cell wall polysaccharides in dragon fruit pulp. Di Cagno *et al.* (2016) investigated how to improve the shelf life, rheological, organoleptic and functional properties of cactus pear puree. Moßhammer et al. (Moßhammer *et al.,* 2006) summarized the physical and chemical properties of cactus pear and their potential applications.

2 (Extraction) The active ingredients in cactus require rational extraction techniques to obtain them. This cluster contains a series of extractions and characterizations of the active/valuable components of the cactus. The process of polysaccharide research generally includes extraction, separation, purification and purity determination. Among them, extraction is related to polysaccharide yield, structure and conformation. Separation and purification further improve the purity of polysaccharides, and their success and effectiveness will be directly related to the feasibility and credibility of subsequent structural studies. Cactus polysaccharides are polar macromolecules. Extraction is usually done by degreasing and decolorizing the raw material and then extracting it with water, salt or diluting alkali at different temperatures. The extracts are concentrated and then precipitated by centrifugation with precipitating agents (e.g. acetone, ethanol, etc.). The precipitated part is usually concentrated under reduced pressure or processed by membrane separation or ultrafiltration, etc., and then cold dried to obtain crude polysaccharide. According to the nature of the polysaccharide to be extracted and the purpose of the study, the extraction agent and extraction conditions are selected. A water-based solution extraction method is often used, or extraction with hot or cold dilute acid or dilute alkali. Avoid using strong acids and bases for extraction to prevent the breakage of glycosidic bonds.

3 # 3 (Water treatment) This cluster contains mainly a series of papers on using cactus raw materials for water treatment. Nharingo *et al.* (2015) investigated the potential use of cactus powder for coagulation-flocculation processes, especially for the adsorption and removal of lead ions. Fox et al. (Fox *et al.,* 2012) also attempted the removal of As (V) from water with cactus mucilage. Asnam et al.

(Asnam *et al.,* 2022) attempted a composite of the cactus extract with sodium alginate. This composite has promise as an adsorbent material for anhydrous treatment.

4 (Bioactive compound) There is some overlap between the papers in this cluster and #1 and #6, which mainly contain a series of investigations on the active ingredients of cactus. For example, Nuñez-López *et al.* (2013) investigated the physicochemical, nutritional and antidiabetic properties of *Opuntia ficus-indica* at different stages of maturation. Armenta and Peña-Valdivia (Armenta *et al.,* 2009) investigated the variation of polysaccharides in *Opuntia matudae* fruits at different stages of ripening.

5 (Enzyme) This cluster consists of two main aspects. The first is the use of enzymes to enhance the extraction. For example, Kim et al. proposed an enzyme-assisted extraction method for improving the extraction and recovery of bioactive materials from cactus. The other category is the potential of cactus extracts in neurological applications. Huang *et al.* (2008 b) investigated the protective effect of cactus polysaccharides on H_2O_2-induced cortical and hippocampal damage in rats.

6 (Mucilage) This cluster contains mainly a series of papers on cactus mucilage. For example, cactus mucus is used to prepare bio-packaging films (Makhloufi *et al.,* 2022). Cactus mucilage can also modify the physicochemical properties of sorghum starch (Rivera-Corona *et al.,* 2014).

7 (Cladode) In addition to the fruit of the cactus, the cactus cladode is the most commonly investigated organ. In early investigations, the relationship between cactus cladode growth and the environment was brought into focus (Nerd *et al.,* 1991; Nobel *et al.,* 1995). Later, how to extract polysaccharides in cactus cladode became the main direction of interest (Sánchez-Hernández *et al.,* 2006; Ciriminna *et al.,* 2019).

8 (Prickly pear) This topic contains only two papers. Ninio *et al.* (2003 b) monitored changes in sugar, acid and volatile components in *Cereus peruvianus* (L.) Miller fruit at different stages of ripening. Habibi *et al.* (2004) detected arabinogalactan in the pericarp of *Opuntia ficus-indica*.

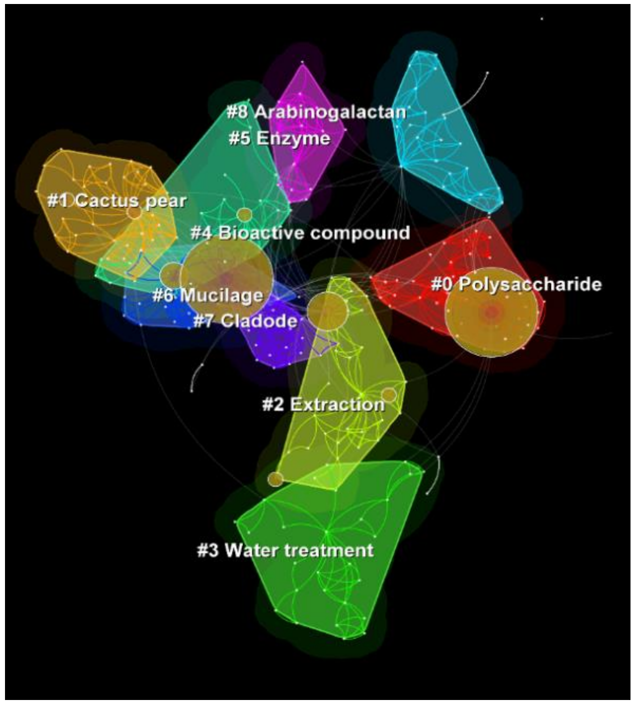

Figure 7. Grouping of keywords for polysaccharides from cactus.

Conclusions

In recent years, polysaccharides have shown significant promise in developing food, pharmaceutical, agricultural and cosmetic industries. As an edible and medicinal plant, cactus polysaccharides have a variety of important medicinal and edible values. Currently, the focus of cactus polysaccharides is mainly on immunomodulatory, antioxidant, hypoglycemic, antitumor and hepatoprotective properties. We analyzed the research process on cactus polysaccharides using a bibliometric approach and obtained the following main analytical conclusions:

(1) The paper on polysaccharides from cactus in the core collection on Web of Science dates back to 1991. Since 2002, this topic has entered a stable phase, with papers published yearly. Starting from 2017, this topic entered a period of significant growth.
(2) Not only have a large number of papers on polysaccharides from cactus published in Carbohydrate Polymers, but the academic community has also recognized these papers.
(3) Materials science-related journals, especially polymer-related journals, started publishing papers on polysaccharides from cactus recently.
(4) Cactus polysaccharides and mucilage can be potentially used as materials for water treatment, so this topic has also been published in water environment/water treatment-related journals in the last two years.
(5) The topic began in Plant Sciences and covered a range of plant and biology-related areas through 2000. Since 2003, cactus polysaccharides have entered Food Science & Technology. After that, this topic started to be cross-researched with chemistry and pharmacology.
(6) Mexico significantly contributed to this topic, contributing 18.1% of the papers. Both China and USA contributed >7% of the papers.
(7) Only one network of cooperation occupies this topic. This collaborative network includes a series of Mexican universities and research institutions.

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(8) Cladode and the cactus fruit are the most commonly used organs to be extracted for polysaccharides.
(9) The extraction principle of the hot water method is similar to that of the acid method, in which the cell wall is ruptured by hot water or acidic solution to release polysaccharides.
(10) Enzymatic, ultrasonic and microwave-assisted methods have been used for extract cactus polysaccharides via breaking the cell wall.

The above analysis shows that bibliometrics is a powerful statistical technique for the analysis of research trends on a topic. We believe that this analytical technique can be used to further analyze topics related to cactus, such as the progress of cactus extraction process.

ETHICS STATEMENT

Not applicable

CONSENT FOR PUBLICATION

Not applicable

AVAILABILITY OF SUPPORTING DATA

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

COMPETING INTERESTS

The authors declare that they have no competing interests

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AUTHOR CONTRIBUTIONS

Conceptualization, Y.Z. and L.F.; methodology, L.F; software, P.Z.; validation, Y.Z. and P.Z.; formal analysis, Y.Z. and P.Z.; investigation, Y.Z.; resources, L.F.; data curation, Y.Z.; writing—original draft preparation, Y.Z. and P.Z.; writing—review and editing, L.F.; visualization, L.F.; supervision, L.F.; project administration, L.F.

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