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Review

Exploring Cactus Mucilage for Sustainable Food Packaging: A Bibliometric Review of a Decade of Research

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Abstract: This review presents a bibliometric analysis of the research landscape on cactus mucilage and its application in biodegradable films for food packaging. The objective was to identify scientific trends, key contributors, and emerging research areas from 2012 to 2022. Original scientific and review articles were retrieved from the Web of Science database and analyzed using VOSviewer software to map co-authorship, keyword co-occurrence, and country collaboration networks. The analysis revealed that Tunisia, the United States, Germany, and Luxembourg, along with their research institutions, are among the most productive contributors in this field. The study also identified leading authors and journals that focus on the development of cactus-based biodegradable films. Common research topics included extraction methods, film formulation, and evaluations of physical, chemical, and functional properties relevant to food packaging. The results emphasize the growing scientific interest in cactus mucilage as a renewable and sustainable alternative to synthetic polymers. This review provides insights into the current state of the field and highlights opportunities for innovation and collaboration in the development of environmentally friendly food packaging technologies.

Keywords: biodegradable films; hydrocolloids; natural polymers; *Opuntia ficus-indica*; scientific mapping

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1. Introduction

In recent years, synthetic polymers have created a major challenge for the world's population due to their excessive use in the industrial and domestic sectors and issues related to environmental pollution. Synthetic materials have an extensive degradation cycle, which can take several years to decompose, so food packaging developed with these polymers is considered highly harmful to the environment [1].

An alternative to minimizing these environmental impacts is the use of natural biopolymers in the development of biodegradable films. Biopolymers are obtained from renewable sources of animal and plant origin, including proteins such as collagen, chitosan, gelatin, and polysaccharides such as starch, pectin, and cellulose, among others [2–4]. These natural

polymers have been gaining ground in scientific circles, mainly in the biodegradable and flexible packaging segment, presenting potential for application in food. Another important factor is that the life cycle of renewable sources is shorter, contributing positively to environmental sustainability [5,6].

A renewable source for obtaining natural polymers is the cactus (*Opuntia ficus-indica*), belonging to the Cactaceae family, originally from the American continent, more precisely from Mexico, which was introduced in the northeast of Brazil around 1880 in the state of Pernambuco. It is considered an exotic plant with a high number of species, which reflects its high genetic variation due to the different agroclimatic conditions of the regions where it is native. Furthermore, the cactus is made up of cladodes that can be used to obtain mucilage [7].

Cactus mucilage, extracted from the cladode of *Opuntia ficus-indica*, has gained prominence as a promising alternative in the development of sustainable packaging solutions due to its unique physicochemical properties, such as its high water retention capacity, natural safety, and heteropolysaccharide composition that provides moisture barrier characteristics and flexibility to biodegradable films. In addition, cactus mucilage is an abundant, renewable, and low-cost raw material, presenting biodegradability and non-toxicity, which makes it especially suitable for applications in the food packaging industry that seek to reduce the environmental impact caused by artificially synthetic polymers [8,9].

The combination of mucilage with other biopolymers, such as starch, gelatin, chitosan, and plasticizers, appears with the purpose of optimizing the hydrophilic–hydrophobic and mechanical characteristics of polymeric films. For example, starch-based biopolymers have been successfully optimized through advanced fabrication techniques to enhance water vapor barrier properties, tensile strength, and biodegradability, demonstrating their potential in sustainable packaging applications [10]. Biodegradable films are thin polymeric layers formed by a dry (e.g., extrusion) or wet (casting) process. They are generally independent materials used as primary packaging in foods, with the purpose of preserving and extending the shelf life of the packaged product [11–13].

Over the last few years, there have been major advances in the extraction of cactus mucilage and its use as a biopolymer in the development of biodegradable films and coatings, and these perspectives are accompanied by an increasing number of technical documents and scientific studies on the subject [13–15]. Depending on the large amount of information available, the use of data extraction and synthesis tools becomes extremely relevant. The bibliometric method is based on the quantitative analysis of structures, characteristics, and potential relationships between publications in the same area. VOSviewer is visual analysis software widely applied in this bibliometric field as it has the ability to display both results in the form of timeline maps as well as the cooperation network between these data [16].

Bibliometric analyses have been increasingly utilized across diverse scientific disciplines [17–19] as a means to evaluate and quantify research output within specific topics or fields, often relying on data from one or multiple indexing platforms. These analyses allow for the visualization of research trends and connections through interactive graphical representations. Considering the rising interest in sustainable materials to replace synthetic polymers and the promising potential of cactus mucilage in this domain, the present review seeks to systematically explore the scientific literature on the application of cactus mucilage in the formulation of biodegradable films using a bibliometric methodology. Specifically, this review seeks to identify research trends, key contributors, collaboration networks, and thematic focuses over the past decade. By doing so, it intends to highlight knowledge gaps, promote a better understanding of the current state of the art, and guide future investigations in the area of biodegradable food packaging.

2. Database and Methods

The review was carried out using a mixed research methodology based on bibliometric analysis and literature review. The literature review consisted of the following topics: "Main natural polymers combined with cactus mucilage to form biodegradable films" and "Trends and future perspectives on the application of cactus mucilage films (*Opuntia ficus-indica*) in foods".

The bibliometric analysis began with a search on the Web of Science (WoS) data platform (www.webofknowledge.com) to analyze global scientific production regarding biodegradable cactus mucilage films in the last 10 years (2012–2022). In this study, we used the search terms "cactus mucilage*" or "cactus mucilage film*" or "cactus mucilage*" or "mucilage of Opuntia ficus indica*" or "mucilage extraction from Opuntia ficus indica*" or "cladode mucilage*" or "opuntia mucilage*" or "based films of cactus mucilage*" or "cactus mucilage extraction*" or "mucilage polymer*" to filter the search in the database (WoS). For the search, the topic criterion was used, thus ensuring the broadest return of works that presented the search expressions in the title, abstract, keywords, and Keywords Plus. Subsequently, the results were refined into "articles" and "reviews", obtaining a total of 90 scientific articles and 3 reviews. The methodological procedure adopted to conduct the bibliometric analysis is summarized in Figure 1.

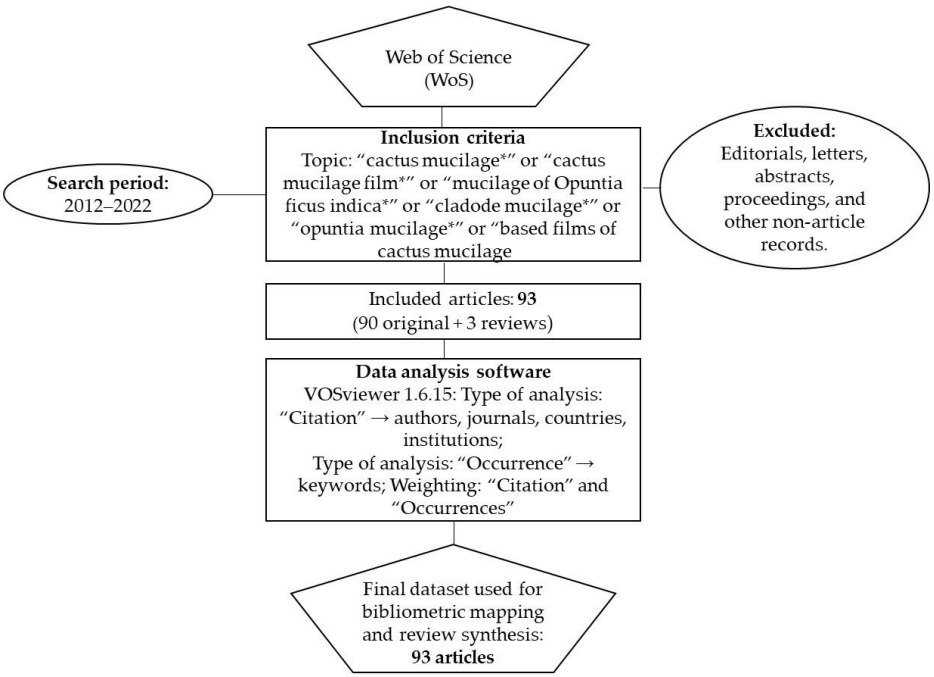


Figure 1. Flowchart illustrating the methodological procedure adopted to conduct the bibliometric analysis.

Then, the data obtained from WoS were analyzed using the program VOSviewer, version 1.6.15 (www.vosviewer.com, accessed on 10 January 2023) [20,21], to create bibliometric graphic mapping and network visualization, in which "citation" was used as a type of analysis to obtain the most cited authors, publications, periodicals, institutions and countries and "occurrence" was used to obtain the keywords with the highest occurrence in the analyzed period, both without taking into account the weight and strength of the link for the ranking of results in the program. After obtaining the graphs, the weight "citation" was used for the results obtained from this type of analysis and "occurrences" was used for the keywords. Furthermore, the OriginPro version 8 program (www.originlab.com,

accessed on 25 January 2023) was used to visualize the analyzed data and draw a global graph showing the distribution of articles by year.

3. Results and Discussions of Bibliometric Analysis

The search method in the database selected for the research (WoS) allowed us to obtain a total of 93 works in the last 10 years (2012–2022), including 90 scientific articles and three review articles (Figure 2). The number of annual articles on the development of biodegradable films using cactus mucilage as a natural polymer has increased over the years, with more comprehensive growth in 2021 and 2022, with 15 and 17 articles, respectively. Cactus mucilage as a biopolymer in the production of packaging is a topic that is still little explored, which justifies the low number of articles published; however, recent research has shown a greater interest among researchers in explaining this area, promoting new future perspectives for changing this scenario.

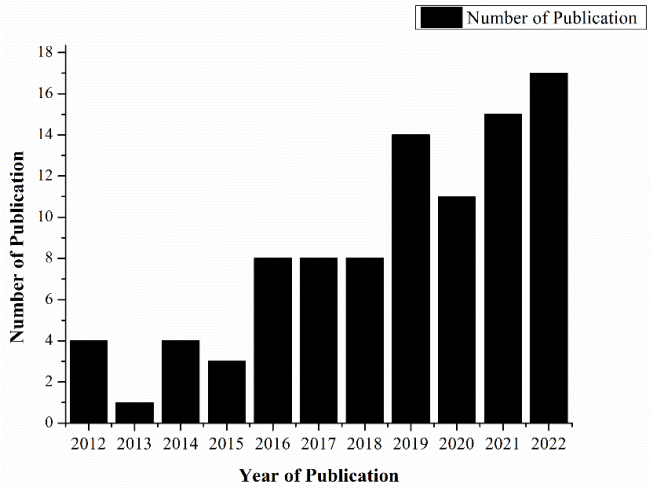


Figure 2. Yearly publication trends concerning the application of cactus mucilage as a biopolymer in biodegradable film production based on data from the Web of Science (WoS) database.

In 2012, the first article published was on the extraction of plant biopolymers, highlighting guar gum, locust bean gum, and cactus mucilage, in which they were combined and used in the treatment of wastewater in the cosmetics industry [22]. In 2016, there was a concentration of studies related to ways of extracting mucilage from cladodes of *Opuntia ficus-indica*. Felkai-Haddache et al. [23] used the microwave-assisted extraction technique combined with the response surface methodology, with the purpose of extracting cactus mucilage, and observed a significant increase in the process yield, indicating the viability of the techniques under study.

As of 2017, there was an increasing focus on the application of cactus mucilage in the development of biodegradable films, emphasizing the combination of mucilage with other biopolymers, such as chitosan, polyvinyl alcohol, and plasticizing agents, aiming to improve the mechanical, hydrophobic, and hydrophilic characteristics of the films developed [7,24]. In 2022, studies became more consistent in the development of biodegradable packaging with active properties. Makhloufi et al. [6] developed active packaging using polysaccharides from cactus mucilage and seaweed agar and observed that the films produced exhibited good mechanical properties, good protection against UV light, good thermal stability, and moderate antioxidant activity. Therefore, the authors consider it a low-cost and environmentally friendly option for the development of active materials for food packaging.

In order to determine the results for the 20 most cited countries in the last 10 years, with an emphasis on research on the extraction of cactus mucilage and its application

in biodegradable films, the cooperation networks between the countries were analyzed (Figure 3). Four different clusters were observed, with Clusters 1 and 2 having the largest numbers of countries, both comprising six countries each. Cluster 1 included the United States of America (144 citations) while Cluster 2 included Tunisia (165 citations), and these were the countries with the highest citation rates. The high rate of research citations observed for the country of Tunisia was already expected, given that in this country there is a very high genetic diversity for *Opuntia ficus-indica* cacti, [25,26] favoring the expansion of research that involves the extraction of mucilage using different extraction techniques, in addition to its use as a biopolymer in the development of biodegradable packaging.

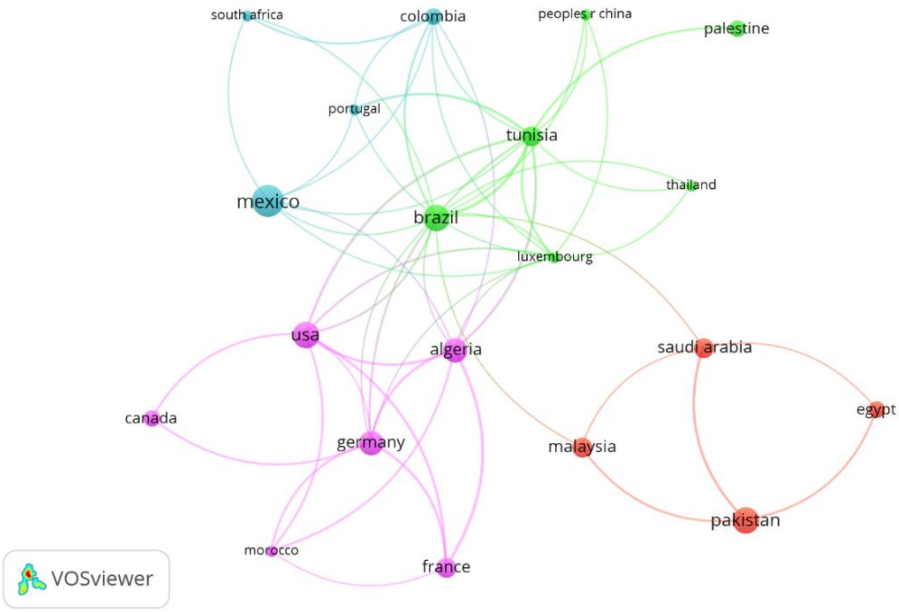


Figure 3. Visualization map of the 20 most cited countries in cactus mucilage research and its application in biodegradable films based on bibliometric analysis from the Web of Science database (2012–2022). The map is divided into four distinct clusters, with Cluster 1 (pink) and Cluster 2 (green) including the largest number of countries (six each), featuring nations such as the United States and Tunisia, respectively—both with the highest citation rates. Cluster 3 (blue) and Cluster 4 (red) include countries with lower citation frequencies, such as Mexico, South Africa, Palestine, and Egypt. The color-coded clusters represent collaboration patterns among countries based on co-authorship networks.

Brazil was one of the countries that occupied Cluster 2, ranking in the seventh position with the highest citation rate (74); in addition, there was greater interaction for this country with 12 countries, highlighting the United States, Algeria, and Germany (Cluster 1); Tunisia, Luxembourg, Thailand, and Palestine (Cluster 2); Mexico, Colombia, and South Africa (Cluster 3); and Malaysia and Saudi Arabia (Cluster 4), indicating that researchers from Brazil carry out scientific research together, promoting an expansion of information sharing with international researchers. Some studies involving these connections were based on the extraction of cactus cladode mucilage as a new natural structuring material for nanoencapsulation [27] and the development of biodegradable films containing cactus mucilage, chitosan, and polyvinyl alcohol (PVA) in different concentrations [24].

In Clusters 3 and 4, there were countries with lower citation rates, highlighting Palestine, Egypt, and Portugal, with eight, four, and three citations, respectively. The countries described present low scientific production, with the development of a maximum of two articles in the last 10 years, which may suggest limited research activity on cactus mucilage and its inclusion in biodegradable films in these countries. However, it is important to emphasize that such data may have resulted from the contributions of a single

researcher affiliated with these nations and therefore do not necessarily reflect a broader national scientific interest in the topic. The citation index is related to the number of articles produced, so the greater the scientific production is, the greater the percentage of citations will be; in addition, it allows us to refine the discrimination of the impact of publications by experienced researchers on the existing knowledge in their areas [28].

Figure 4 illustrates the results obtained from the 20 most cited institutions in the last 10 years. The institutions that demonstrated the greatest relevance for the article citation index were the University of South Florida (124), National Institute of Research and Physico-chemical Analysis (108), Luxembourg Institute of Science Technology (108), and Polytechnical Institute National Mexico (102). Therefore, it was found that the institutions with the highest citation rates belonged to countries such as the United States, Tunisia, Luxembourg, and Mexico, where they were characterized as the main research centers in the area of mucilage extraction and its application in film development. Furthermore, the University of Béjaïa organization showed greater interaction with the second cluster, indicating a strong influence on the relationship within the cooperation networks, which revealed that the scholarship holders of this institution were more independent. This independence may be associated with a higher proportion of single-author or limited-co-author publications, or research not strongly tied to international collaborations, suggesting a more autonomous scientific approach compared to other institutions.

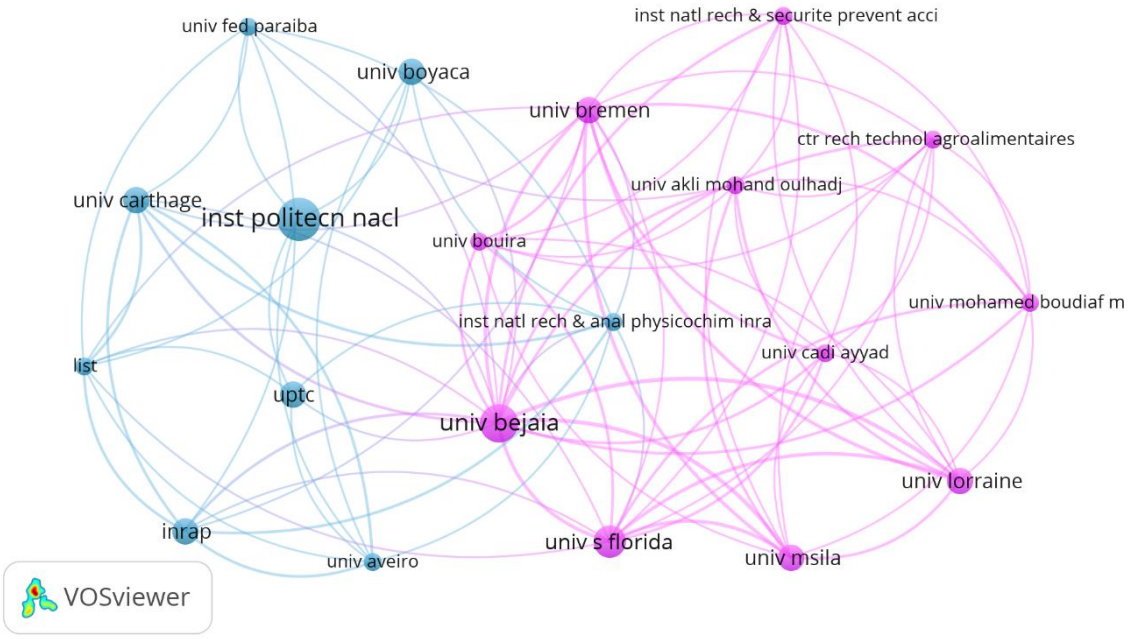


Figure 4. Collaborative network of the 20 most cited institutions in cactus mucilage research and its application in biodegradable films according to a bibliometric analysis conducted in the Web of Science database (2012–2022). Note: VOSviewer was used. Institutions: Federal University of Paraiba (Brazil); National Institute of Research and Physico-chemical Analysis (Tunisia); University of South Florida (United States); Luxembourg Institute of Science Technology (Luxembourg); Aveiro University (Portugal); INRAP—National Institute for Preventive Archaeological Research (France); National Institute of Research and Safety for the Prevention of Work Accidents (France); Polytechnical Institute National Mexico (Mexico); University of Boyacá (Colombia); University of Béjaïa (Algeria); University of Bremen (Germany); University of Lorraine (France); Carthage University (Tunisia); Pedagogical and Technological University of Colombia (Colombia); University of Bouira (Algeria); University of M'sila (Algeria); Université Akli Mohand Oulhadj (Algeria); Cadi Ayyad University (Morocco); Centre de Recherche en Technologies Agro-Alimentaires (Algeria); University Mohamed Boudiaf (Algeria).

Institutions such as the Federal University of Paraiba and Aveiro University were classified as some of the organizations with the least notoriety in relation to the number of citations, a fact justified by the development of recent scientific research, highlighting the publication of articles on the development of active packaging with *Opuntia ficus-indica* mucilage and its applications in food in the year 2022. Generally, to increase the citation rate of articles recently published by institutions, a longer period of time is needed for them to be cited and thus gain credibility for researchers from other countries, favoring the expansion of the collaborative network between countries that carry out similar research [29].

According to an analysis of the WoS database, Table 1 shows the 18 journals with the highest number of citations on cactus mucilage and its application as a natural polymer in biodegradable films in the last 10 years (2012–2022). Of the eighteen main journals, five were from the Netherlands, four from the United Kingdom, four from Switzerland, two from the United States of America, two from Saudi Arabia, and one from Taiwan. Therefore, 50% were European journals, 33% Asian, and 17% North American. The journal *Carbohydrate Polymers*, published by Elsevier, topped the ranking in first place, with two articles and 148 citations, receiving an average of 74 citations per published article.

Table 1. The top 18 most cited journals in cactus mucilage research and its application in biodegradable films, according to a bibliometric analysis conducted in the Web of Science database (2012–2022).

Journal	Country	Citations	Publications	Impact Factor *	CiteScore
Carbohydrate Polymers	United Kingdom	148	2	11.20	18.90
Environmental Science & Technology	United States	93	2	11.40	16.70
LWT- Food Science and Technology	Switzerland	73	3	6.00	6.70
Separation and Purification Technology	Netherlands	70	2	8.60	12.70
Food Chemistry	United Kingdom	58	3	8.80	14.90
Coatings	Switzerland	40	1	3.40	4.70
Journal of Electroanalytical Chemistry	Netherlands	31	1	4.50	7.50
Colloids and Surfaces B: Biointerfaces	Netherlands	31	1	5.80	11.00
Water Science and Technology	United Kingdom	31	1	2.70	3.40
Saudi Pharmaceutical Journal	Saudi Arabia	31	1	4.56	5.70
International Journal of Biological Macromolecules	Netherlands	28	2	8.20	14.50
Journal of the Taiwan Institute of Chemical Engineers	Taiwan	24	1	5.70	9.60
Food Packaging and Shelf Life	Netherlands	17	1	8.00	12.90
Journal of Food Measurement and Characterization	United States	13	2	3.06	3.00
Molecules	Switzerland	11	1	4.60	6.70
International J. of Environmental Analytical Chemistry	United Kingdom	8	1	2.73	5.45
Saudi Journal of Biological Sciences	Saudi Arabia	5	1	4.05	5.30
Polymers	Switzerland	4	1	5.00	6.60

* 2022 impact factor.

The high leadership rating of *Carbohydrate Polymers* was already expected, given that it is a journal that mainly covers studies on the exploration of polysaccharides that have current or potential application in areas such as bioplastics, biomaterials, and biodegradable packaging for food, the latter area being the focus of this review.

Publications using cactus mucilage as a polysaccharide in the preparation of films as parts of food packaging were reported on by Gheribi et al. [7], who developed edible films

combining *Opuntia ficus-indica* mucilage with different plasticizers and found that the type of plasticizer significantly influenced the physical, thermal, mechanical, and barrier properties of the films. Manhivi et al. [30] conducted a study on the aqueous extraction process of mucilage from cactus cladodes, aiming to characterize both its chemical composition as well as its thermal behavior and viscosity profile, with a focus on potential uses within the food industry.

The journal *Environmental Science & Technology* was the second most relevant journal in the area, with its works totaling 93 citations, with an impact factor of 11.40 and CiteScore 16.70. The scope of this journal consists of rigorous studies of complex environmental phenomena, particularly with regard to fate, transport, and transformation in natural and engineered systems, while facilitating the solution of critical environmental problems. Fox et al. [31] developed a coagulation–flocculation system using a combination of cactus mucilage and ferric salt to remove toxic compounds from water. Other studies have aimed to address the environmental impact, potential health risks to consumers, and the economic challenges linked to the use of synthetic plastics. In this context, researchers have explored the application of natural biopolymers recognized for being renewable, biodegradable, and, in some cases, edible as sustainable alternatives in the development of food packaging materials [32].

LWT—Food Science and Technology and *Separation and Purification Technology* were ranked as the third and fourth most cited journals, respectively. These journals presented impact factors of 6.00 and 8.60, with three and two publications addressing the topic. Their main areas of publication were biochemistry, food science and technology, chemical engineering, environmental engineering, microbiology, and nutrition. Among these scientific areas, the study by Carmona et al. [33] stands out, and this study carried out the encapsulation of mucilage from the cactus *Opuntia ficus-indica* using maltodextrin as an encapsulating agent (EA) and evaluated the performance of the microparticles as colorants in yogurt. Otálora et al. [34] extracted mucilage from cladodes of *Opuntia ficus-indica* and created a coacervate combining mucilage and gelatin and observed that this system had bioactive properties with application in the food industry.

Polymers is a journal that publishes articles and reviews on innovative and significant advances in physics, chemistry, and polymer technology with an emphasis on packaging application and development. In this bibliometric analysis, the journal with the lowest citation rate was considered, and this result was justified due to the publication of recent articles (2022), limiting citation by other researchers. One of the focuses of the publications of *Polymers* was reported by Todhanakasem et al. [35], who evaluated formulations of active films composed of cactus mucilage added with probiotic extract (*E. faecium* FM11-2 from fermented chicken isolates) and applied to slices of minimally processed apples. The results demonstrated that the active film resulted in a greater shelf life extension, preserving the original characteristics of the packaged product.

Figure 5 presents the leading authors contributing to research on cactus mucilage extraction and its application in biodegradable packaging.

Dr. Rim Gheribi was considered the most cited and influential author in the last 10 years, with three articles published, receiving 165 citations. The author is a researcher at the National School of Agronomy and Food Industries at the University of Lorraine, where she has been carrying out research with polysaccharides, highlighting cactus mucilage, and its use as a material for food packaging, considered an ecologically correct alternative. Furthermore, the researcher has a collaborative network with multidisciplinary research, developed with international researchers from countries such as France, Italy, Luxembourg, and Tunisia.

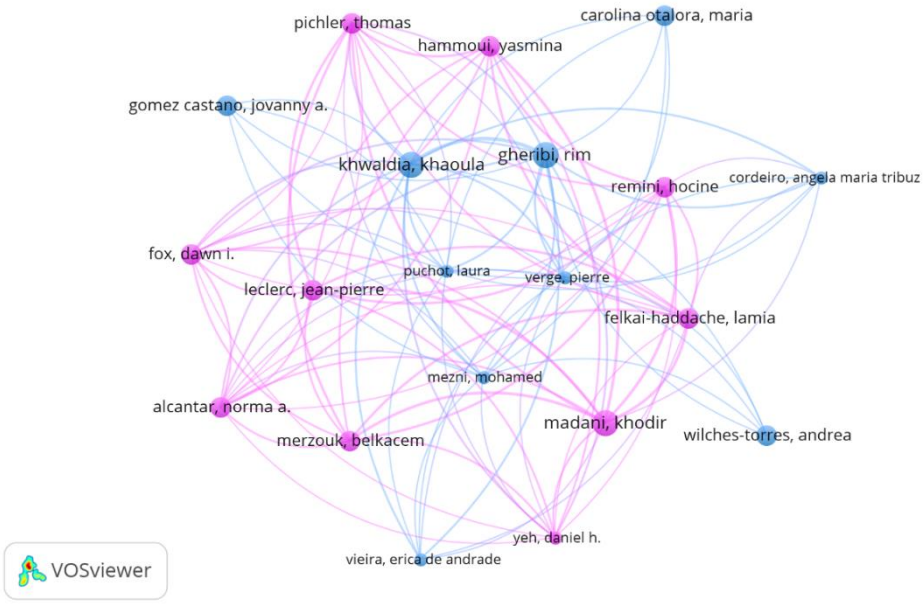


Figure 5. Collaboration network linking the 20 most cited authors in studies on cactus mucilage and its application in biodegradable films based on a bibliometric analysis of the Web of Science database (2012–2022).

Researcher Dr. Khaoula Khwaldia is Tunisian, from the Institut National de Recherche et d'Analyse Physico-Chimique, and is ranked as the second most cited author (164 citations). She has experience in the area of biotechnological and food processes, working on investigating the valorization of biopolymers for inclusion in food packaging, as well as studying the interaction mechanisms between biodegradable packaging and food. Furthermore, she has co-authored, with researcher Dr. Rim Gheribi, papers on experimental studies on the optimization of the physical, mechanical, and thermal properties of cactus mucilage films combined with other natural polymers. Dr. Pierre Verge, affiliated with the Luxembourg Institute of Science and Technology (LIST), maintains a collaborative relationship with the two aforementioned authors and ranks as the third most influential researcher in this field, with a total of 108 citations. All the researchers mentioned above made up the second cluster.

In relation to the first cluster, it was made up of ten researchers; among the most influential were Dr. Norman Alcantar, Dr. Dawn Fox, and Dr. Daniel Yeh, three researchers from the University of South Florida, who together produced five publications and 253 quotes. In addition was Dr. Khodir Madani, Professor and researcher at the University of Bejaia, considered the tenth most cited author (59 citations); the focus of the research carried out by this author was based on the extraction of mucilage from cladodes of *Opuntia ficus-indica* using green technologies such as microwave-assisted extraction. It appears that the composition of this cluster consisted mainly of researchers from the United States and Algeria, corroborating data from the countries most cited in research on cactus mucilage (Figure 2).

Regarding the most cited articles (Table 2), a research article produced by Otalora et al. stands out in first place with 133 citations [36]. The researchers explained the importance of microencapsulation of bioactive pigments, using *Opuntia ficus-indica* mucilage and maltodextrin as coating materials, in order to obtain natural microcapsules for application in food. Gheribi et al. [7] developed the second article with the highest citation index (108 citations). In this research, they reported the potential of cactus mucilage to form edible films and coatings, and they created biodegradable films using cactus mucilage with the inclusion of different plasticizers in order to investigate the effects of

different plasticizers on film properties, as well as to design new applications of this sustainable biomaterial.

Table 2. List of the 20 most cited articles on cactus mucilage and its use in biodegradable film development based on a bibliometric analysis of the Web of Science database (2012–2022), organized in descending order of citation count.

Publication	Year	NC	Journal	Reference
Microencapsulation of betalains obtained from cactus fruit (*Opuntia ficus-indica*) by spray drying using cactus cladode mucilage and maltodextrin as encapsulating agents	2015	133	*Food Chemistry*	Otalora et al. [36]
Development of plasticized edible films from *Opuntia ficus-indica* mucilage: A comparative study of various polyol plasticizers	2018	108	*Carbohydrate Polymers*	Gheribi et al. [7]
The polysaccharide and low molecular weight components of Opuntia ficus indica cladodes: Structure and skin repairing properties	2017	54	*Carbohydrate Polymers*	Di Lorenzo et al. [37]
Extraction and characterization of mucilage from wild species of Opuntia	2014	51	*Journal of Food Process Engineering*	Rodríguez-González et al. [38]
Spray drying microencapsulation of betalain rich extracts from Escontria chiotilla and Stenocereus queretaroensis fruits using cactus mucilage	2019	43	*Food Chemistry*	Delia et al. [39]
Cactus Mucilage for Food Packaging Applications	2019	41	*Coatings*	Gheribi; Khwaldia, [40]
Valorization of Opuntia monacantha (Willd.) Haw. cladodes to obtain a mucilage with hydrocolloid features: Physicochemical and functional performance	2019	37	*International Journal of Biological Macromolecules*	Dick et al. [41]
Zeaxanthin nanoencapsulation with Opuntia monacantha mucilage as structuring material: Characterization and stability evaluation under different temperatures	2018	32	*Colloids and Surfaces A-Physicochemical and Engineering Aspects*	Campo et al. [27]
Physical Characterization of Biodegradable Films Based on Chitosan, Polyvinyl Alcohol and Opuntia Mucilage	2017	29	*Journal of Polymers and the Environment*	Dominguez-Martinez et al. [24]
Mucilage from cladodes of Opuntia spinulifera Salm-Dyck: chemical, morphological, structural and thermal characterization	2018	22	*Cyta-Journal of Food*	Madera-Santana et al. [42]

Table 2. *Cont.*

Publication	Year	NC	Journal	Reference
Microwave optimization of mucilage extraction from Opuntia ficus indica Cladodes	2016	20	*International Journal of Biological Macromolecules*	Felkai-Haddache et al. [23]
Enhancement of the physical, mechanical and thermal properties of cactus mucilage films by blending with polyvinyl alcohol	2019	17	*Food Packaging and Shelf Life*	Gheribi et al. [11]
Preparation, study and characterization of complex coacervates formed between gelatin and cactus mucilage extracted from cladodes of *Opuntia ficus-indica*	2019	17	*LWT- Food Science and Technology*	Otalora et al. [34]
Seasonal characterization of nutritional and antioxidant properties of *Opuntia ficus-indica* [(L.) Mill.] mucilage	2021	14	*Food Hydrocolloids*	Messina et al. [43]
Mucilage of spineless cactus in the composition of an edible coating for minimally processed yam (*Dioscorea* spp.)	2019	13	*Journal of Food Measurement and Characterization*	Morais et al. [44]
Effect of *Opuntia ficus-indica* Mucilage Edible Coating in Combination with Ascorbic Acid, on Strawberry Fruit Quality during Cold Storage	2021	11	*Journal of Food Quality*	Liguori et al. [45]
Preparation and physicochemical characterization of softgels Cross-Linked with cactus mucilage extracted from cladodes of *Opuntia ficus-indica*	2019	11	*Molecules*	Caballero et al. [46]
Cactus Mucilage as a Coating Film to Enhance Shelf Life of Unprocessed Guavas (*Psidium guajava* L.)	2015	10	*Acta Horticulturae*	Zegbe et al. [14]
Development of Bioactive *Opuntia ficus-indica* Edible Films Containing Probiotics as a Coating for Fresh-Cut Fruit	2022	4	*Polymers*	Todhanakasem et al. [35]
Thermoplastic Starch (TPS) Films Added with Mucilage from Opuntia Ficus Indica: Mechanical, Microstructural and Thermal Characterization	2020	4	*Materials*	Scognamiglio et al. [47]

NC: Number of citations.

The third most cited article (54 citations), written by Di Lorenzo et al. [37], was a characterization of the cladode mucilage of *Opuntia ficus-indica* (L.), and the authors observed the presence of high-molecular-weight components such as a linear galactan polymer and a highly branched xyloarabinan, compounds that perform antioxidant activity and healing. The article entitled "Extraction and Characterization of Mucilage From Wild Species of Opuntia" [38] is in fourth position, with 51 citations. This study aimed to characterize the mucilage obtained from six Opuntia species and to identify the optimal

extraction conditions that preserve its original chemical structure. The authors reported that the optimal extraction condition that promoted the highest yield was the option that used a 50% ethanol solution in a 1:1 (m/v) ratio, a temperature of 22 °C, and a precipitation of the mucilage with an ethanol solution to 96% in a ratio of 1:4 (v/v). Furthermore, the mucilage obtained had the potential to be used for commercial purposes in biopolymers and additives in the food industry.

The cited articles produced by Delia et al. [39] and Gheribi and Khwaldia [40] presented 43 and 41 citations, respectively. In the first article, the researchers focus on green technologies; they tested the capacity of cactus mucilage as an encapsulating agent in the microencapsulation of pigments from the pulp and skin of Escontria chiotilla and Stenocereus queretaroensis through a spray dry process. The second is a review article that highlights the application of mucilage in the food packaging industry through the development of films and coatings. The authors highlight the significance of these cactus-derived biomaterials because of their functional characteristics and their potential to maintain food quality and prolong shelf life.

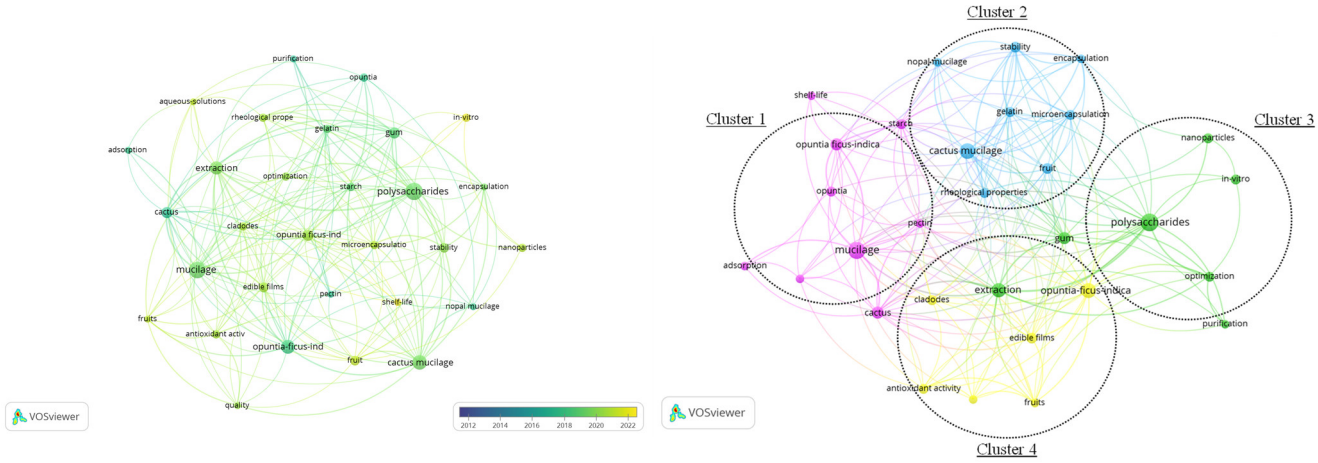
The other themes were based on extraction and characterization techniques of *Opuntia ficus-indica* mucilage [27,41,42]. Felkai-Haddache et al. [23] explained microwave-assisted extraction, which is a technology for obtaining natural biopolymers, with emphasis on cactus mucilage, and observed that this method has advantages in saving extraction time, the amount of solvent used, and the consumption of energy. Messina et al. [43] evaluated the technological, nutritional, and bioactive properties of cactus mucilage (*Opuntia ficus-indica*) and found good nutritional properties, highlighting the presence of polyunsaturated acids (EPA and DHA); in addition, high antioxidant power was observed, being considered as an option for potential application at the industrial level in the food or nutraceutical sector.

The other experimental articles classified among the 20 most cited articles were focused on the development of bioactive films for application in food, containing cactus mucilage (*Opuntia ficus-indica*) and other biopolymers, highlighting starch, chitosan, and polyvinyl alcohol [11,24,35,47]. Meanwhile, Ligório et al. [45] developed an edible coating using cactus mucilage combined with ascorbic acid and applied it to strawberry fruits in order to increase shelf life during refrigerated storage. Morais et al. [44] produced coatings with cactus mucilage and applied it to minimally processed yam, and the results indicated that the bio-coating reduced dehydration and maintained the visual and sensorial quality of the yam slices.

Figure 6 presents the keyword occurrence analysis from the past decade (2012–2022), considering only those keywords with a minimum of three occurrences. Figure 6a represents an overlaid visualization map, demonstrating the keywords with a minimum number of occurrences of three in the 93 publications on cactus mucilage and its application in biodegradable films. The bibliometric analysis showed that most of the keywords appeared in the period from 2016 to 2022, which probably revealed that films developed with cactus mucilage represented an emerging area, indicating greater interest among researchers in the extraction of polysaccharide biopolymers and their application in the packaging sector as alternatives to synthetic materials.

The keywords were divided into four clusters (Figure 6b), with the words with the highest occurrences being found in Clusters 1 and 3, highlighting "Polysaccharides" with a total of thirteen occurrences, "mucilage" with twelve occurrences, and "*Opuntia ficus-indica*" with nine occurrences. Furthermore, the trend of these keywords with greater occurrence has been emerging since 2016, indicating once again that research on cactus mucilage for the development of biodegradable films in the last decade (2012–2022) has been limited,

making it, if necessary, an expansion of this research as it remains directly linked to studies on extraction, characterization, and microencapsulation technologies [27,39].



(**a**) (**b**)

Figure 6. The 30 most frequently occurring keywords in cactus mucilage research and their application in the development of biodegradable films based on a bibliometric analysis of the Web of Science database (2012–2022): (**a**) overlay visualization; (**b**) network visualization.

In Cluster 4, the focus of the keywords was mainly on obtaining mucilage from *Opuntia ficus-indica* cladodes and the formation of biodegradable films and their application in food. It was found that in recent years, some researchers had focused on incorporating probiotics and other active plant extracts to create edible biodegradable films, promoting the emergence of new ecologically sustainable technologies. Todhanakasem et al. [35] developed cactus mucilage-based films with the inclusion of a probiotic strain of Enterococcus faecium FM11-2 as an active component, and the results indicated that the film played a significant active role in extending food stability, minimizing weight loss. and maintaining the freshness of freshly cut apple slices. Makhloufi et al. [6] emphasized that the development of films from renewable materials for food packaging is a significant research area within sustainable development, focusing on replacing traditional plastics and reducing environmental impacts.

4. Main Natural Polymers Combined with Cactus Mucilage to Form Biodegradable Films

There is a wide variety of natural polymers used in the production of biodegradable packaging, among which starch, agar, alginate, gelatin, chitosan, and pectin are the most prominent [48]. Figure 7 summarizes the main characteristics of these biopolymers. Starch, a naturally abundant polysaccharide obtained from plants such as corn, potato, and rice, is known for its good film-forming and rheological properties [49,50]. Gelatin, a protein-based polymer, offers high transparency and rigidity, but has low water resistance [51,52]. Chitosan, derived from chitin, is biodegradable and exhibits antimicrobial activity and excellent mechanical and barrier properties [53–56]. Pectin, another plant-derived polysaccharide, is valued for its gelling ability but often requires blending with other polymers to improve mechanical strength [57–59]. Agar and alginate, both extracted from seaweed, are also used in films due to their gelling and barrier properties, though their pure forms may have limitations in flexibility and resistance [60–64].

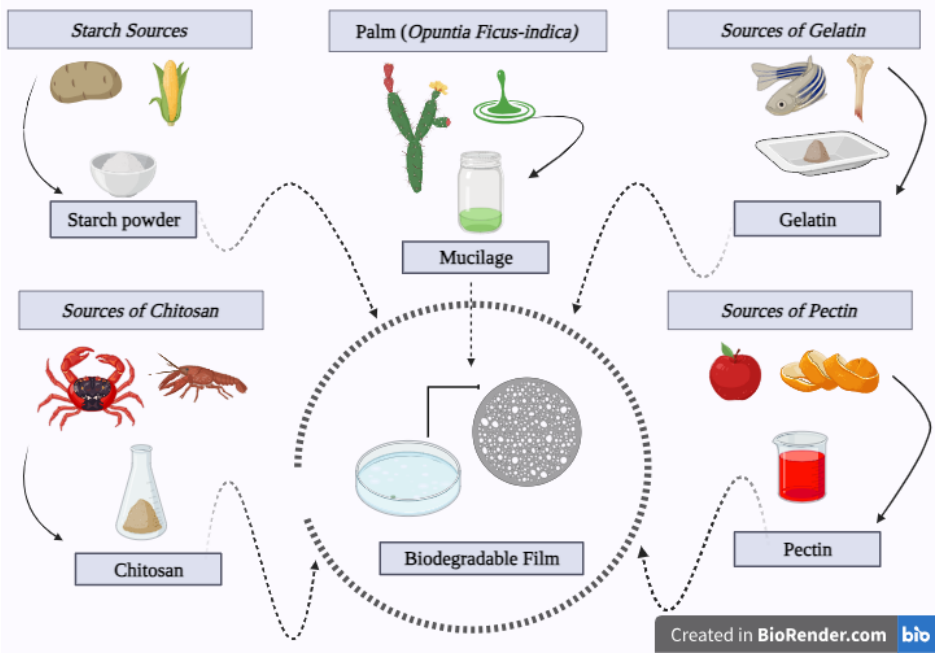


Figure 7. Overview of biopolymers utilized in the production of biodegradable films intended for food applications.

Polymer blending is widely recognized as a flexible and economical approach to create polymeric materials with enhanced overall performance. This strategy helps offset or eliminate the limitations of individual polymers, resulting in stronger biodegradable films with improved barrier, solubility, mechanical, and thermal properties [65]. Some researchers have reported that cactus mucilage (*Opuntia ficus-indica*) is an ideal candidate in combination with other natural polymers in order to obtain a more efficient packaging to protect the packaged food [11,66].

Todhanakasem et al. [35] developed six biodegradable film formulations, in which they used a combination of cactus mucilage, gelatin, and two types of plasticizers, sorbitol and glycerol, in addition to a probiotic strain (Enterococcus faecium FM11-2). The authors concluded that the film formulation containing cactus mucilage, gelatin, glycerol, and the probiotic was considered the most ideal option, due to its presenting the best physicochemical and physical properties, and consequently played a significant active role in prolonging the stability of food, minimizing weight loss, and maintaining the freshness of freshly cut apple slices.

Lira-Vargas et al. [67] investigated biodegradable films prepared from a blend of cactus mucilage, gelatin, and beeswax, characterizing them through microscopy, morphology, thickness, transparency, tensile strength, and permeability to water vapor, oxygen, and carbon dioxide. The results indicated that this packaging system has great potential for application in the area of the post-harvest conservation of horticultural products as it demonstrates good mechanical resistance and gas barrier properties.

Sandoval et al. [68] evaluated formulations combining mucilage from Mexican *Opuntia ficus-indica* with pectin and glycerol to identify the optimal mixture for use in food products aimed at preserving quality and extending shelf life. The authors demonstrated in their research that the combination of these polymers resulted in low permeability to water vapor (1.63×10^{-11} g·m^{-1}·s^{-1}·Pa^{-1}), which may prevent moisture exchange and reduce product deterioration, and, consequently, extend the shelf life of packaged products.

The blending of cactus mucilage with other natural polymers has been shown to result in significant modifications to the functional properties of the resulting films. These changes include improvements in mechanical strength, barrier performance, and bioactivity, which

are often limited in films produced with a single polymer component. The synergistic interactions between the mucilage and biopolymers such as gelatin, chitosan, and pectin contribute to the formation of a more homogeneous and compact polymeric matrix, as reported by Lira-Vargas et al. [67] and Olicón-Hernández et al. [69]. Additionally, such combinations can enhance the water vapor barrier and antimicrobial performance, which is critical for extending the shelf life of perishable food products. Therefore, incorporating cactus mucilage into polymer blends does not merely act as a filler but actively contributes to the functional improvement of biodegradable films, reinforcing its relevance in the development of more efficient and sustainable food packaging systems.

5. Trends and Future Perspectives on the Application of Cactus Mucilage Films (*Opuntia ficus-indica*) in Foods

The extraction of mucilage from *Opuntia ficus-indica* offers an alternative that, beyond its cultural, economic, and socio-environmental advantages, shows significant potential as a biopolymer for developing biodegradable packaging. This approach could help reduce the reliance on synthetic polymers used by packaging industries. Recently, one of the main focus areas in the research of biodegradable films with cactus mucilage consists of its application in perishable vegetables and fruits, aiming to increase the shelf life and maintain the original characteristics of the products [35,44].

Biodegradable films improve the shelf life of food by protecting it against internal and external factors such as microorganisms, humidity, gases, and temperature. Additionally, films can serve as carriers for various ingredients and components including vitamins, minerals, antioxidants, antimicrobials, and nutraceuticals while also functioning as protective barriers [70]. Makhloufi et al. [6] developed a film containing cactus mucilage and agar, using the casting technique, and observed good antioxidant activity, characterizing it as an active packaging for food recommended for food products with low moisture content.

The packaging industry is a growing area, where there are several opportunities for new research involving the production of active or smart films. The development of these packaging systems using cactus mucilage (*Opuntia-Ficus-indica*) as a polymeric material is a promising alternative to favor innovation possibilities, encourage the cultivation and use of previously undervalued plants, and minimize environmental problems [15,71].

One of the future perspectives is to direct the field of application of biodegradable cactus mucilage films to dairy products, specifically aged cheeses, as there is still no research in the literature, being an alternative to diversify this area, as well as towards promoting the conservation and quality of products packaged with this system. The beneficial properties of cactus mucilage discussed in this review can play important roles in the packaging field. Therefore, its extraction must be better explored by relevant industries in the sector, as well as maintaining partnerships between researchers, research institutions, and industries, in order to explore these trends in detail and promote innovative alternatives for consumers.

6. Conclusions

Bibliometric analysis presented itself as an important tool to identify the main scientific productions of cactus mucilage and its application in the development of biodegradable films. This review has pointed out that cactus (*Opuntia ficus-indica*) is a species considered a source of mucilage, present mainly in cladodes, being characterized as a promising biopolymer in the production of biodegradable films. Robust collaborations were identified among researchers, countries, and organizations involved in studying mucilage-based film formulations, facilitating the widespread dissemination of knowledge.

In this context, the number of publications on biodegradable films has increased significantly since 2019 due to both the great interest in mucilage derived from cactus in

order to use it as a biopolymer in the formation of biodegradable packaging as well as the growing awareness of the environmental impacts generated by synthetic polymers used in the traditional packaging system.

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References

1. Saratale, R.G.; Cho, S.-K.; Saratale, G.D.; Kadam, A.A.; Ghodake, G.S.; Kumar, M.; Bharagava, R.N.; Kumar, G.; Kim, D.S.; Mulla, S.I.; et al. A comprehensive overview and recent advances on polyhydroxyalkanoates (PHA) production using various organic waste streams. *Bioresour. Technol.* **2021**, *325*, 124685.
2. Chen, L.; Qing, T.; Chen, X.; Ren, W.; Zhang, H. Fabrication and evaluation of biodegradable multi-cross-linked mulch film based on waste gelatina. *Chem. Eng. J.* **2021**, *419*, 129639. [CrossRef]
3. Menossi, M.; Mario, C.; Vera, A.; Claudia, C. Current and emerging biodegradable mulch films based on polysaccharide bio-composites. A review. *Agron. Sustain. Dev.* **2021**, *41*, 41–53. [CrossRef]
4. Xu, Y.; Li, Q.; Man, L. Bamboo-derived carboxymethyl cellulose for liquid film as renewable and biodegradable agriculture mulching. *Int. J. Biol. Macromol.* **2021**, *192*, 611–617. [CrossRef]
5. Sid, S.; Mor, R.S.; Kishore, A.; Sharanagat, V.S. Bio-sourced polymers as alternatives to conventional food packaging materials: A review. *Trends Food Sci. Technol.* **2021**, *111*, 87–104. [CrossRef]
6. Makhloufi, N.; Chougui, N.; Rezgui, F.; Benramdane, E.; Silvestre, A.J.D.; Freire, C.S.R.; Vilela, C. Polysaccharide-based films of cactus mucilage and agar with antioxidant properties for active food packaging. *Polym. Bull.* **2022**, *79*, 11369–11388. [CrossRef]
7. Gheribi, R.; Puchot, L.; Verge, P.; Jaoued-Grayaa, N.; Mohamed, M.; Habibi, Y.; Khaoula, K. Development of plasticized edible flms from Opuntia fícus indica mucilage: A comparative study of various. *Carbohydr. Polym.* **2018**, *190*, 204–211. [CrossRef]
8. Contreras-Padilha, M.; Rodríguez-García, M.E.; Gutiérrezcortez, E.; Valderrama-Bravo, M.C.; Rojas-Molina, J.I.; Riveramunoz, E.M. Physicochemical and rheological characterization of Opuntia fícus mucilage at three diferente maturity stages of cladode. *Eur. Polym. J.* **2016**, *78*, 226–234. [CrossRef]
9. Taheri, A.; Jafari, S.M. Gum-based nanocarriers for the protection and delivery of food bioactive compounds. *Adv. Colloid Interface Sci.* **2019**, *269*, 277–295. [CrossRef]
10. Biswak, A.K.; Chakraborty, S.; Saha, J.; Panda, P.K.; Pradhan, S.K.; Behera, P.K.; Misra, P.K. Process Optimization, Fabrication, and Characterization of a Starch-Based Biodegradable Film Derived from an Underutilized Crop. *ACS Food Sci. Technol.* **2024**, *8*, 1844–1863. [CrossRef]
11. Gheribi, R.; Gharbi, M.A.; Ouni, M.E.; Khwakdia, K. Enhancement of the physical, mechanical and thermal properties of cactus mucilage films by blending with polyvinyl alcohol. *Food Packag. Shelf Life* **2019**, *22*, 100386. [CrossRef]
12. Kumar, L.; Deshmukh, R.K.; Gaikwad, K.K. Antimicrobial packaging film from cactus (*Cylindropuntia fulgida*) mucilage and gelatine. *Int. J. Biol. Macromol.* **2022**, *251*, 596–605. [CrossRef] [PubMed]
13. Mannai, F.; Mechi, L.; Alimi, F.; Alsukaibi, A.K.D.; Belgacem, M.N.; Moussaoui, Y. Biodegradable composite films based on mucilage from *Opuntia ficus-indica* (*Cactaceae*): Microstructural, functional and thermal properties. *Int. J. Biol. Macromol.* **2023**, *252*, 126456. [CrossRef] [PubMed]
14. Zegbe, J.A.; Mena-Covarrubias, J.; Domínguez-Canales, V.S.I. Cactus mucilage as a coating film to enhance shelf life of unprocessed guavas (*Psidium guajava* L.). *Acta Hortic.* **2015**, *1067*, 423–427. [CrossRef]
15. Vieira, E.A.; Cordeiro, A.M.T.M. Bioprospecting and potential of cactus mucilages: A bibliometric review. *Food Chem.* **2023**, *401*, 134121. [CrossRef]
16. Zhang, X.; Zhang, Y.; Wang, Y.; Brian, D. Research progress and hotspot analysis for reactive nitrogen flows in macroscopic systems based on a CiteSpace analysis. *Ecol. Model.* **2021**, *443*, 109456. [CrossRef]

17. Liu, L.; Zou, G.; Zou, Q.; Li, S.; Bao, Z.; Jin, T.; Liu, D.; Du, L. It is still too early to promote biodegradable mulch film on a large scale: A bibliometric analysis. *Environ. Technol. Innov.* **2022**, *27*, 102487. [CrossRef]
18. Ribeiro, N.G.; Xavier-Santos, D.; Campelo, P.H.; Guimarães, J.T.; Pimentel, T.C.; Duarte, M.C.K.H.; Freitas, M.Q.; Esmerino, E.A.; Silva, M.C.; Cruz, A.G. Dairy foods and novel thermal and non-thermal processing: A bibliometric analysis. *Innov. Food Sci. Emerg. Technol.* **2022**, *76*, 102934. [CrossRef]
19. Prabakusuma, A.S.; Wardono, B.; Fahlevi, M.; Zulham, A.; Sunarno, M.T.D.; Syukur, M.; Aljuaid, M.; Saniuk, S.; Apriliani, T.; Pramoda, R. A bibliometric approach to understanding the recent development of self-sufficient fish feed production utilizing agri-food wastes and by-products towards sustainable aquaculture. *Heliyon* **2023**, *9*, e17573. [CrossRef]
20. Eck, N.J.V.; Waltman, L. Visualizing Bibliometric Networks. *Meas. Sch. Impact* **2014**, *3*, 285–320.
21. Dirpan, A.; Ainani, A.F.; Djalal, M. A bibliometrics visualization analysis of active packaging system for food packaging. *Heliyon* **2023**, *9*, e18457. [CrossRef] [PubMed]
22. Carpinteyro-Urban, S.; Vaca, M.; Torres, L.G. Can Vegetal Biopolymers Work as Coagulant–Flocculant Aids in the Treatment of High-Load Cosmetic Industrial Wastewaters? *Water Air Soil Pollut.* **2012**, *223*, 4925–4936. [CrossRef]
23. Felkai-Haddache, L.; Dahmoune, F.; Remini, H.; Lefsih, K.; Mouni, L.; Madani, K. Microwave optimization of mucilage extraction from Opuntia ficus indica Cladodes. *Int. J. Biol. Macromol.* **2016**, *84*, 24–30. [CrossRef]
24. Dominguez-Martinez, B.M.; Martínez-Flores, H.E.; Berrios, J.D.J.; Otoni, C.G.; Wood, D.F.; Velazquez, G. Physical Characterization of Biodegradable Films Based on Chitosan, Polyvinyl Alcohol and Opuntia Mucilage. *J. Polym. Environ.* **2017**, *25*, 683–691. [CrossRef]
25. Zoghlami, N.; Chrita, I.; Bouamama, B.; Gargouri, M.; Zemni, H.; Ghorbel, A.; Mliki, A. Molecular based assessment of genetic diversity within Barbary fig (*Opuntia ficus indica* (L.) Mill.) in Tunisia. *Sci. Hortic.* **2007**, *13*, 134–141. [CrossRef]
26. Amani, E.; Marwa, L.; Hichem, B.S.; Amel, S.-H.; Ghada, B. Morphological variability of prickly pear cultivars (*Opuntia* spp.) established in ex-situ collection in Tunisia. *Sci. Hortic.* **2019**, *248*, 163–175. [CrossRef]
27. Campo, C.; Dick, M.; Santos, P.P.; Costa, T.M.H.; Paese, K.; Guterres, S.S.; Rios, A.O.; Flôres, S.H. Zeaxanthin nanoencapsulation with Opuntia monacantha mucilage as structuring material: Characterization and stability evaluation under different temperatures. *Colloids Surf. A Physicochem. Eng. Asp.* **2018**, *558*, 410–421. [CrossRef]
28. Araújo, C.G.S.; Sardinha, A. H-index of cited articles: A contribution to the evaluation of the scientific production of researchers. *Braz. J. Sports Med.* **2011**, *17*, 358–362.
29. Barbosa Júnior, L.G.; Almeida, F.L.C.; Luna, L.C.; Castro, M.P.J.; Almeida, E.C. Cotton oil and flour: A bibliometric study. *Holos* **2021**, *2*, 1–17.
30. Manhivi, V.E.; Venter, S.; Amonsou, E.O.; Kudanga, T. Composition, thermal and rheological properties of polysaccharides from amadumbe (*Colocasia esculenta*) and cactus (*Opuntia* spp.). *Carbohydr. Polym.* **2018**, *195*, 163–169. [CrossRef]
31. Fox, D.I.; Stebbins, D.M.; Alcantar, N.A. Combining Ferric Salt and Cactus Mucilage for Arsenic Removal from Water. *Environ. Sci. Technol.* **2016**, *50*, 2507–2513. [CrossRef] [PubMed]
32. Beikzadeh, S.; Khezerlou, A.; Jafari, S.M.; Pilevar, Z.; Mortazavian, A.M. Seed mucilages as the functional ingredients for biodegradable films and edible coatings in the food industry. *Adv. Colloid Interface Sci.* **2020**, *280*, 102164. [CrossRef] [PubMed]
33. Carmona, J.C.; Robert, P.; Vergara, C.; Sáenz, C. Microparticles of yellow-orange cactus pear pulp (*Opuntia ficus-indica*) with cladode mucilage and maltodextrin as a food coloring in yogurt. *LWT* **2020**, *138*, 110672. [CrossRef]
34. Otálora, M.C.; Gómez-Castaño, J.A.; Wilches-Torres, A. Preparation, study and characterization of complex coacervates formed between gelatin and cactus mucilage extracted from cladodes of *Opuntia ficus-indica*. *LWT* **2019**, *112*, 108234. [CrossRef]
35. Todhanakasem, T.; Boonchuai, P.; Ayutthaya, P.I.; Suwapanich, R.; Hararak, B.; Wu, B.; Young, B.M. Development of Bioactive *Opuntia ficus-indica* Edible Films Containing Probiotics as a Coating for Fresh-Cut Fruit. *Polymers* **2022**, *14*, 5018. [CrossRef]
36. Otálora, M.C.; Carriazo, J.G.; Iturriaga, L.; Nazareno, M.A.; Osorio, C. Microencapsulation of betalains obtained from cactus fruit (*Opuntia ficus-indica*) by spray drying using cactus cladode mucilage and maltodextrin as encapsulating agents. *Food Chem.* **2015**, *187*, 174–181. [CrossRef]
37. Di Lorenzo, F.; Silipo, A.; Molinaro, A.; Parrilli, M.; Schiraldi, C.; D'Agostino, A.; Izzo, E.; Rizza, L.; Bonina, A.; Bonina, F.; et al. The polysaccharide and low molecular weight components of Opuntia ficus indica cladodes: Structure and skin repairing properties. *Carbohydr. Polym.* **2017**, *157*, 128–136. [CrossRef]
38. Rodríguez-González, S.; Martínez-Flores, H.E.; Chávez-Moreno, C.K.; Macías-Rodríguez, L.I.; Zavala-Mendoza, E.; Garnica-Romo, M.G.; Chacón-García, L. Extraction and Characterization of Mucilage From Wild Species of Opuntia. *J. Food Process. Eng.* **2014**, *37*, 285–292. [CrossRef]
39. Delia, S.-C.; Chávez, G.M.; León-Martínez, F.M.; Araceli, S.-G.P.; Irais, A.-L.; Franco, A.-A. Spray drying microencapsulation of betalain rich extracts from Escontria chiotilla and Stenocereus queretaroensis fruits using cactus mucilage. *Food Chem.* **2019**, *272*, 715–722. [CrossRef]
40. Gheribi, R.; Khwaldia, K. Cactus Mucilage for Food Packaging Applications. *Coatings* **2019**, *9*, 655. [CrossRef]

41. Dick, M.; Dal Magro, L.; Rodrigues, R.C.; Rios, A.; De, O.; Flôres, S.H. Valorization of Opuntia monacantha (Willd.) Haw. cladodes to obtain a mucilage with hydrocolloid features: Physicochemical and functional performance. *Int. J. Biol. Macromol.* **2019**, *123*, 900–909. [CrossRef] [PubMed]
42. Madera-Santana, T.J.; Vargas-Rodríguez, L.; Núñez-Colín, C.A.; González-García, G.; Peña-CaballerO, V.; Núñez-Gastélum, J.A.; Gallegos-Vázquez, C.; Rodríguez-Núñez, J.R. Mucilage from cladodes of Opuntia spinulifera Salm-Dyck: Chemical, morphological, structural and thermal characterization. *CyTA-J. Food* **2018**, *16*, 650–657. [CrossRef]
43. Messina, C.M.; Arena, R.; Morghese, M.; Santulli, A.; Liguori, G.; Inglese, P. Seasonal characterization of nutritional and antioxidant properties of *Opuntia ficus-indica* [(L.) Mill.] mucilage. *Food Hydrocoll.* **2021**, *111*, 106398. [CrossRef]
44. Morais, M.A.S.; Fonseca, K.S.; Viégas, E.K.D.; Almeida, S.L.; Maia, R.K.M.; Silva, V.N.S.; Simões, A.N. Mucilage of spineless cactus in the composition of an edible coating for minimally processed yam (*Dioscorea* spp.). *J. Food Meas. Charact.* **2019**, *3*, 2000–2008. [CrossRef]
45. Liguori, G.; Gaglio, R.; Settanni, L.; Inglese, P.; D'anna, F.; Miceli, A. Effect of *Opuntia ficus-indica* Mucilage Edible Coating in Combination with Ascorbic Acid, on Strawberry Fruit Quality during Cold Storage. *J. Food Qual.* **2021**, *1*, 9976052. [CrossRef]
46. Caballero, L.R.C.; Wilches-Torres, A.; Cárdenas-Chaparro, A.; Gómez Castaño, J.A.; Otálora, M.C. Preparation and Physicochemical Characterization of Softgels Cross-Linked with Cactus Mucilage Extracted from Cladodes of *Opuntia ficus-indica*. *Molecules* **2019**, *24*, 2531. [CrossRef]
47. Scognamiglio, F.; Gattia, D.M.; Roselli, G.; Persia, F.; Angelis, U.; Santulli, C. Thermoplastic Starch (TPS) Films Added with Mucilage from Opuntia Ficus Indica: Mechanical, Microstructural and Thermal Characterization. *Materials* **2020**, *13*, 1000. [CrossRef] [PubMed]
48. Liu, F.; Chen, Q.; Liu, C.; Ao, Q.; Tian, X.; Fan, J.; Tong, H.; Wang, X. Natural polymers for organ 3D bioprinting. *Polymers* **2018**, *10*, 1278. [CrossRef]
49. Cheng, W.; Sun, Y.; Xia, X.; Yang, L.; Fan, M.; LI, Y.; Wang, L.I.; Qian, H. Effects of β-amylase treatment conditions on the gelatinization and retrogradation characteristics of wheat starch. *Food Hydrocoll.* **2022**, *124*, 107286. [CrossRef]
50. Torres, F.G.; De- La- Torre, G.E. Synthesis, characteristics, and applications of modified starch nanoparticles: A review. *Int. J. Biol. Macromol.* **2022**, *194*, 289–305. [CrossRef]
51. Li, X.; Sha, X.-M.; Yang, H.-S.; Ren, Z.-Y.; Tu, Z.-C. Ultrasonic treatment regulates the properties of gelatin emulsion to obtain high-quality gelatin film. *Food Chem.* **2023**, *18*, 100673. [CrossRef] [PubMed]
52. Tavares, W.S.; Barreto, G.A.V.; Pinto, E.P.; Silva, P.G.B.; Sousa, F.O. Influence of gelatin on the functional characteristics and wound healing potential of chitosan/zein films loaded with ellagic acid nanoparticles. *J. Drug Deliv. Sci. Technol.* **2023**, *88*, 104942. [CrossRef]
53. Hosseini, S.F.; Gómez-Guillén, M.C. A state-of-the-art review on the elaboration of fish gelatin as bioactive packaging: Special emphasis on nanotechnology-based approaches. *Trends Food Sci. Technol.* **2018**, *79*, 125–135. [CrossRef]
54. Bakshi, P.S.; Selvakumar, D.; Kadirvelu, K.; Kumar, N.S. Chitosan as an environment friendly biomaterial—A review on recent modifications and applications. *Int. J. Biol. Macromol.* **2020**, *150*, 1072–1083. [CrossRef]
55. Cazón, P.; Várquez, M. Mechanical and barrier properties of chitosan combined with other components as food packaging film. *Environ. Chem. Lett.* **2020**, *18*, 257–267. [CrossRef]
56. Flórez, E.; Guerra-Rodríguez, P.; Cazón, M.; Vázquez. Chitosan for food packaging: Recent advances in active and intelligent films. *Food Hydrocoll.* **2022**, *124*, 107328. [CrossRef]
57. Hosseini, S.; Parastouei, K.; Khodaiyan, F. Simultaneous extraction optimization and characterization of pectin and phenolics from sour cherry pomace. *Int. J. Biol. Macromol.* **2020**, *158*, 911–921. [CrossRef]
58. Rahmani, Z.; Khodaiyan, F.; Kazemi, M.; Sharifan, A. Optimization of microwave-assisted extraction and structural characterization of pectin from sweet lemon peel. *Int. J. Biol. Macromol.* **2020**, *147*, 1107–1115. [CrossRef]
59. Gupta, R.K.; Guha, P.; Srivastav, P.P. Natural polymers in bio-degradable/edible film: A review on environmental concerns, cold plasma technology and nanotechnology application on food packaging- A recent trends. *Food Chem. Adv.* **2022**, *1*, 100135. [CrossRef]
60. Mostafavi, F.S.; Zaeim, D. Agar-based edible films for food packaging applications—A review. *Int. J. Biol. Macromol.* **2020**, *59*, 1165–1176. [CrossRef]
61. Xiao, Q.; Weng, H.; Ni, H.; Hong, Q.; Lin, K.; Xiao, A. Physicochemical and gel properties of agar extracted by enzyme and enzyme-assisted methods. *Food Hydrocoll.* **2019**, *87*, 530–540. [CrossRef]
62. Ranjbar, M.; Tabrizzad, M.H.A.; Asadi, G.; Ahari, H. Investigating the microbial properties of sodium alginate/chitosan edible film containing red beetroot anthocyanin extract for smart packaging in chicken fillet as a pH indicator. *Heliyon* **2023**, *9*, e18879. [CrossRef]
63. Gheorghita, R.; Gutt, G.; Amariei, S. The use of edible films based on sodium alginate in meat product packaging: An eco-friendly alternative to conventional plastic materials. *Coatings* **2020**, *10*, 166. [CrossRef]

64. Mahcene, Z.; Khelil, A.; Hasni, S.; Akman, P.K.; Bozkurt, F.; Birech, K.; Goudjil, M.B.; Tornuk, F. Development and characterization of sodium alginate based active edible films incorporated with essential oils of some medicinal plants. *Int. J. Biol. Macromol.* **2020**, *15*, 124–132. [CrossRef]
65. Huang, H.-D.; Ren, P.-G.; Zhong, G.-J.; Olah, A.; Li, Z.-M.; Baer, E.; Zhu, L. Promising strategies and new opportunities for high barrier polymer packaging films. *Prog. Polym. Sci.* **2023**, *144*, 101722. [CrossRef]
66. Kamel, S.M. Utilization of Cactus Dear Peels Mucilage as an Edible Coating of Chicken Meat to Prolong its Shelf Life. *Food Sci. Qual. Manag.* **2014**, *18*, 71–77.
67. Lira-Vargas, A.A.; Corrales-Garcia, J.J.E.; Valle-Guadarrama, S.; Pena-Valdivia, C.B.; Trejo-Marquez, M.A. Biopolymeric films based on cactus (*Opuntia ficus-indica*) mucilage incorporated with gelatin and beeswax. *J. Prof. Assoc. Cactus Dev.* **2014**, *16*, 51–70.
68. Sandoval, D.C.G.; Sosa, B.L.; Martínez-Ávila, G.C.G.; Fuentes, H.R.; Abarca, V.H.A.; Rojas, R. Formulation and Characterization of Edible Films Based on Organic Mucilage from Mexican *Opuntia ficus-indica*. *Coatings* **2019**, *9*, 506. [CrossRef]
69. Olicón-Hernández, D.R.; Acosta-Sánchez, A.; Monterrubio-López, R.; Guerra-Sánchez, G. Chitosan and *Opuntia ficus-indica* mucilage as the base of a polymeric edible film for the protection of tomatoes against Rhizopus stolonifera. *Spec. J. Ciên Quím-Bióg.* **2019**, *22*, 1–9.
70. Dhall, R.K. Advances in Edible Coatings for Fresh Fruits and Vegetables: A Review. *Crit. Rev. Food Sci. Nutr.* **2013**, *53*, 435–450. [CrossRef]
71. Cakmak, H.; Ilyasoglu-Buyukkestelli, H.; Sogut, E.; Ozyurt, V.H.; Gumus-Bonacina, C.E.; Simsek, S. A review on recent advances of plant mucilages and their applications in food industry: Extraction, functional properties and health benefits. *Food Hydrocoll. Health* **2023**, *3*, 100131. [CrossRef]

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