



# Polymer-free cyclodextrin and natural polymer-cyclodextrin electrospun nanofibers: A comprehensive review on current applications and future perspectives

Andrea Doderò, Guy Schlatter, Anne Hebraud, Silvia Vicini, Maila Castellano

## ► To cite this version:

Andrea Doderò, Guy Schlatter, Anne Hebraud, Silvia Vicini, Maila Castellano. Polymer-free cyclodextrin and natural polymer-cyclodextrin electrospun nanofibers: A comprehensive review on current applications and future perspectives. Carbohydrate Polymers, 2021, 264, pp.118042. 10.1016/j.carbpol.2021.118042 . hal-03217583

**HAL Id: hal-03217583**

**<https://hal.science/hal-03217583>**

Submitted on 4 May 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Andrea Dodero<sup>1</sup>, Guy Schlatter<sup>2\*</sup>, Anne Hébraud<sup>2</sup>, Silvia Vicini<sup>1</sup>, Maila Castellano<sup>1\*</sup>

<sup>2</sup> Institute of Chemistry and Processes for Energy, Environment and Health (ICPEES), CNRS UMR 7515,  
ECPM – University of Strasbourg, 25 rue Becquerel, 67087, Strasbourg, France

\*corresponding authors: maila.castellano@unige.it  
guy.schlatter@unistra.fr

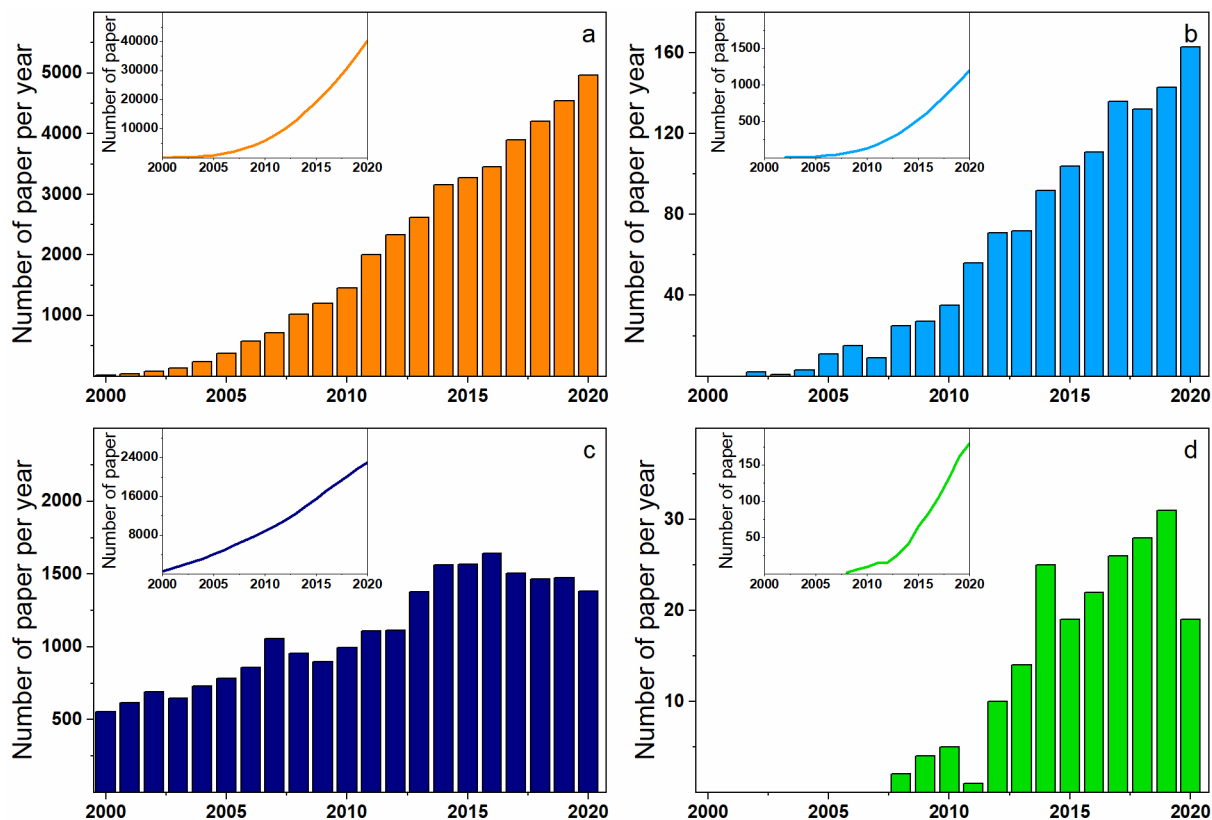
The present review discusses the use of cyclodextrins and their derivatives to prepare electrospun nanofibers with specific features. Cyclodextrins, owing to their unique capability to form inclusion complexes with hydrophobic and volatile molecules, can indeed facilitate the encapsulation of bioactive compounds in electrospun nanofibers allowing fast-dissolving products for food, biomedical, and pharmaceutical purposes, filtering materials for wastewater and air purification, as well as a variety of other technological applications. Additionally, cyclodextrins can improve the processability of naturally occurring biopolymers helping the fabrication of “green” materials with a strong industrial relevance. Hence, this review provides a comprehensive state-of-the-art of different cyclodextrins-based nanofibers including those made of pure cyclodextrins, of polycyclodextrins, and those made of natural biopolymer functionalized with cyclodextrins. To this end, the advantages and disadvantages of such approaches and their possible applications are investigated along with the current limitations in the exploitation of electrospinning at the industrial level.

1

- 28    Electrospinning; Cyclodextrins; Natural biopolymers; Functionalized nanofibers; Inclusion complexes;
- 29    Polycyclodextrins.

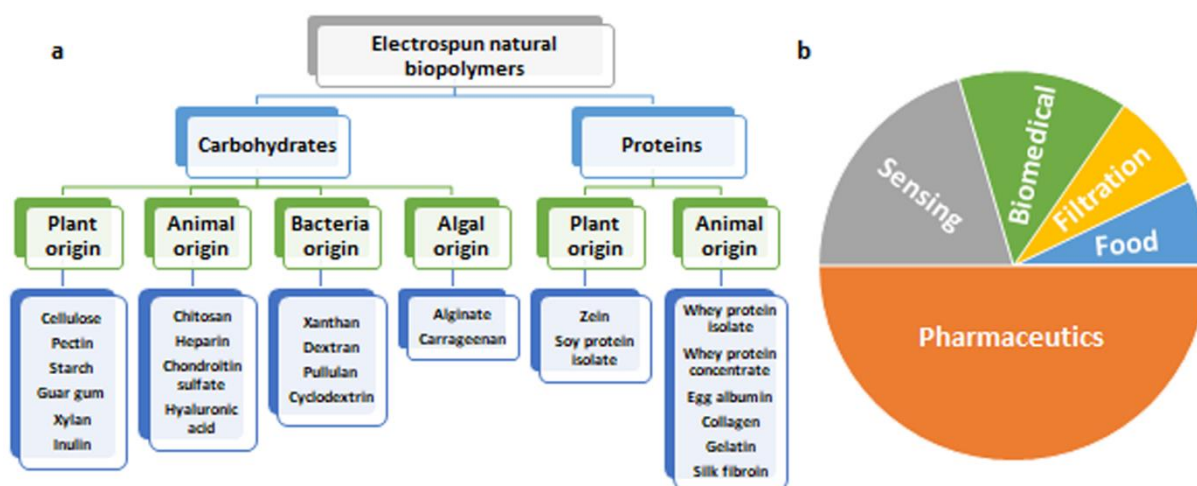
## 1 Introduction

Electrospinning is a simple, versatile, and cost-effective technique that allows the fabrication of polymeric nano- and microfibers starting from a polymer solution or polymer melt (J. Xue et al., 2019). Demonstrated in 1934 by A. Formhals (Anton, 1934), electrospinning started to gain considerable interest from the 2000s and it is nowadays one of the most employed fiber-forming approaches for several purposes (Ahmed et al., 2015; Doderò, Alloisio, Castellano, et al., 2020; Doderò, Brunengo, Castellano, et al., 2020; Doderò, Vicini, Lova, et al., 2020; Tebyetekerwa & Ramakrishna, 2020; Thenmozhi et al., 2017). Among others, electrospun nanofibers can be efficiently used to encapsulate a great variety of molecules, such as drugs, bioactive compounds and nanoparticles (Castellano et al., 2019; Figueiredo et al., 2020; Quirós et al., 2016; Torres-Giner et al., 2016; Wen et al., 2017). In this sense, cyclodextrins (CDs) offer the chance to obtain functionalized nanofibers with high encapsulation efficiency, enhanced thermal stability, water-solubility, and bioavailability of the encapsulated molecules (Costoya et al., 2017; Senthil Muthu Kumar et al., 2019; Topuz & Uyar, 2019). However, cyclodextrin-functionalized nanofibers remain a barely explored research field and, to the best of our knowledge, no commercial products currently exist besides an increasing number of original research work has being recently published. To this regard, Costoya et al. (Costoya et al., 2017) recently reviewed the fabrication of cyclodextrin functional nanofibers, whereas Topuz et al. (Topuz & Uyar, 2019) and Vidal et al. (Patiño Vidal et al., 2021) focused the attention on their pharmaceutical and food packaging applications, respectively. By way of example, Figure 1 reports the number of publications per year in the last two decades (i.e., 2000-2020) concerning electrospinning (Figure 1a), functionalized nanofibrous membranes (Figure 1b), cyclodextrins (Figure 1c) and cyclodextrin-functionalized nanofibrous membranes (Figure 1d).



**Figure 1.** Annual trend of publications regarding (a) electrospinning, (b) functionalization of electrospun nanofibers, (c) cyclodextrins, and (d) cyclodextrin-functionalized electrospun nanofibers. Insets represent the cumulative number of publications. Data has been retrieved from Scopus database.

Among the great variety of commercial polymers that can be electrospun, naturally occurring materials represent an attractive alternative to synthetic ones (Ding et al., 2019; Soares et al., 2018). Indeed, biopolymers, such as polysaccharides and proteins, can be used to fabricate nanofibers with superior biocompatibility, biodegradability, and lower environmental impact compared to industrially derived materials. Nonetheless, their processing is usually more difficult and it requires a series of experimental precautions (Bertasa et al., 2020; Ding et al., 2019; Dodero, Pianella, et al., 2019; Kakoria & Sinha-Ray, 2018; Mendes et al., 2017; Noruzi, 2016). A schematic representation of the most common natural biomaterial-based electrospun mats and their applications is reported in Figure 2.



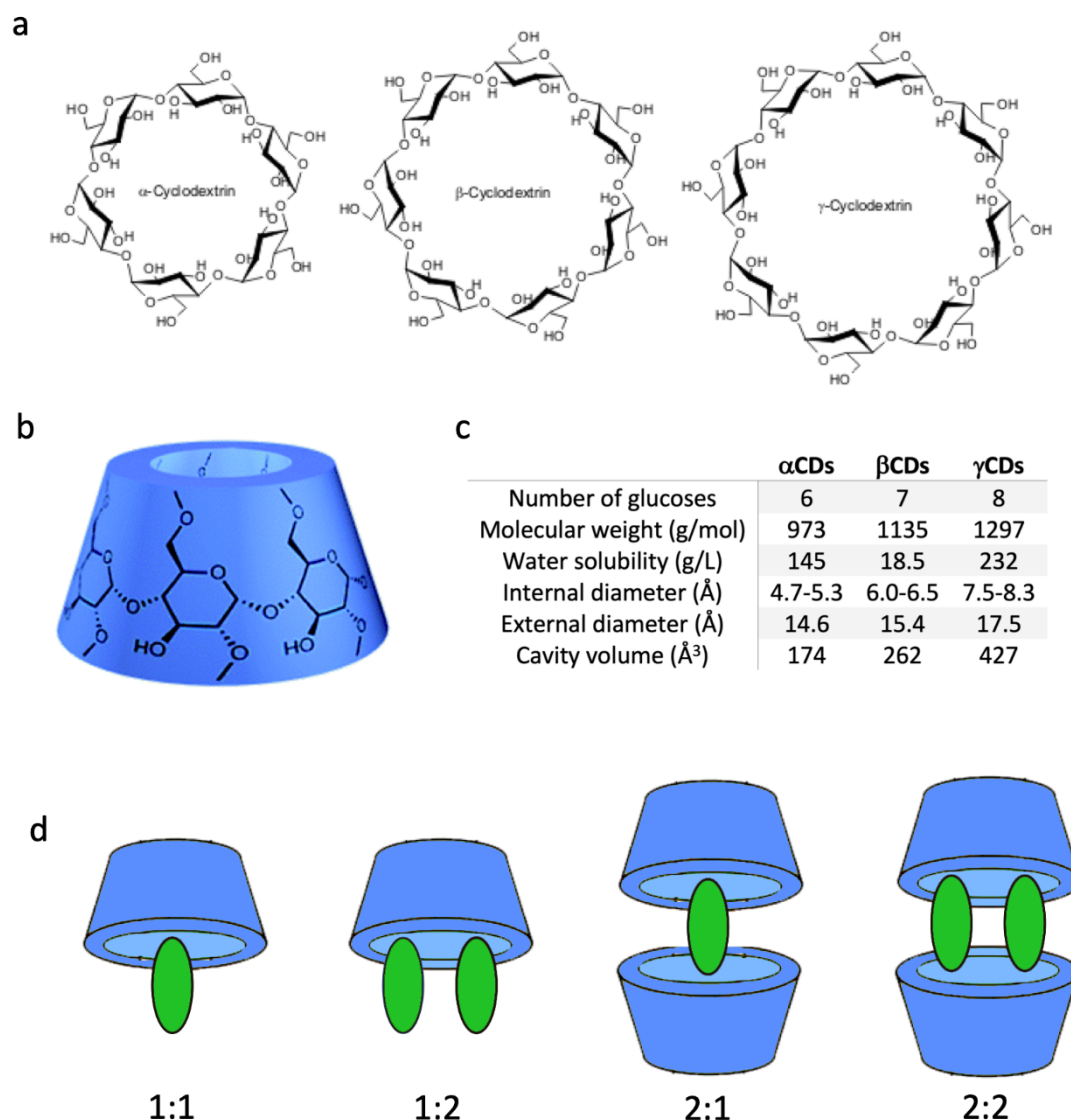
**Figure 2.** (a) Schematic of natural biopolymer-based electrospun membranes depending on the source materials and (b) pie chart representing their main applications according to the Scopus database.

With these premises, aiming to highlight the importance of developing environmentally benign materials, this review aims to provide a comprehensive summary of the recent advances in the preparation of either polymer-free cyclodextrin-based nanofibers, polycyclodextrin-based nanofibers, or natural polymer-based (i.e., polysaccharides and proteins) nanofibers functionalized with cyclodextrins. To this end, after a brief introduction concerning cyclodextrins first and electrospinning then, a critical and complete overview of the current literature is presented and discussed. Finally, a short consideration about the future trends and possibilities is reported together with a conclusion paragraph.

## 2 Cyclodextrins

### 2.1 Structure and Properties

Cyclodextrins consist of cyclic oligosaccharides of glucopyranose assuming the structure of a hollow truncated cone (Figure 3b) (Sá Couto et al., 2015). The inner cavity of this three-dimensional structure is partially hydrophobic owing to the -CH and -CH<sub>2</sub> carbons and ether oxygens, whereas the exterior surface is hydrophilic due to the high number of hydroxyl groups (Szejtli, 1998). Although several types of CDs exist, the most common ones consist of 6, 7, and 8 glucopyranose units and are named  $\alpha$ CDs,  $\beta$ CDs, and  $\gamma$ CDs, respectively, with their structure and main properties reported in Figure 3a-c (Del Valle, 2004; Jansook et al., 2018; Kurkov & Loftsson, 2013).



**Figure 3.** (a) Chemical structure of the most common CDs. (b) Three-dimensional conformation taken by CDs. (c) Summary of the main physical properties of CDs depending on the glucose unit number. (d) Schematics of inclusion complex formation with blue and green objects representing cyclodextrins (i.e., host molecules) and small molecules (i.e., guest molecules). For example, inclusion complexes with a molar ratio 1:1 have been prepared between  $\beta$ CDs and racecadotril (Semalty et al., 2014), with a molar ratio 1:2 between  $\beta$ CDs and naproxen (Grandelli et al., 2013), with a molar ratio of 2:1 between  $\beta$ CDs and carvacrol (Bethanis et al., 2013), and with a molar ratio 2:2 between  $\beta$ CDs and linalool (Ceborska, 2016).

Native CDs are highly crystalline and are known to adopt a cage structure with a herringbone arrangement (Saenger et al., 1998). Typically, they present a low solubility that depends on their size, with  $\beta$ CDs being the less soluble ones (Szejtli, 1998). In order to overcome this processing limitation, CDs have been chemically modified to enhance their water solubility mostly by causing a considerable loss of crystallization. Among others, the most studied are randomly methylated- $\beta$ CDs (M $\beta$ CDs), 2-hydroxypropyl- $\beta$ CDs

99 (HP $\beta$ CDs) and 2-hydroxypropyl- $\gamma$ CDs (HP $\gamma$ CDs) (Crini, 2014; Landy et al., 2012). Remarkably, an  
100 interesting feature of native and modified CDs is represented by their capability to undergo  
101 crosslinking/polymerization reactions leading to water-insoluble cyclodextrin-based polymers (polyCDs)  
102 with tailor-made properties (Blanchemain et al., 2008; Crini, 2014; Morin-Crini & Crini, 2013; Sherje et al.,  
103 2017).

## 105 **2.2 Cyclodextrin Inclusion Complexes**

106 Cyclodextrins are nowadays applied in many industrial sectors (Q. Liu et al., 2020a; Matencio et al., 2020;  
107 Wankar et al., 2020; Ying - Ming Zhang et al., 2020). The main reason for CDs success is related to their  
108 unique ability to form non-covalent host-guest complexes with a variety of small molecules via inclusion in  
109 their hydrophobic cavity (G. Chen & Jiang, 2011; Folch-Cano et al., 2014; Mura, 2015). Depending on both  
110 the type of cyclodextrins and hydrophobic molecules, as well as on the formulation conditions, the  
111 complexation can occur between a host and a guest molecule, a host and two guest molecules, or two hosts  
112 and a guest molecule as represented in Figure 3d (Frömming & Szejtli, 1994; Kim et al., 2006; S. Li & Purdy,  
113 1992; Mohanty et al., 2006; Song et al., 2009). Cyclodextrin inclusion complexes (CD-ICs) are commonly  
114 exploited to protect those molecules that are sensitive to light, oxygen, heat, and chemical reactions, as well  
115 as to increase the water solubility of hydrophobic compounds and to preserve highly volatile  
116 fragrances/flavours. By way of examples, CD-ICs have been widely proposed in food and beverage products  
117 (dos Santos et al., 2017; É. Fenyvesi et al., 2016), in the pharmaceutical and (Jansook et al., 2018) cosmetic  
118 fields (Crini et al., 2018), in the textile industry (Narayanan et al., 2015; Singh & Sahu, 2018), and in  
119 developing filtering materials (Éva Fenyvesi et al., 2020; Q. Liu et al., 2020b).

## 121 **3 Electrospinning and its Use as Encapsulation Technique**

122 The electrospinning (ES) technique consists of the application of a high voltage to a polymer solution, or a  
123 polymer melt, that is usually extruded from a spinneret at a constant rate. Owing to the presence of free  
124 surface charges, the polymeric droplet exiting the spinneret takes the shape of a cone (i.e., Taylor cone) and,  
125 when the repulsive electrostatic forces overcome the liquid surface tension, a continuous jet erupts from the



126 spinneret tip. Hence, solid nano- or microfibers are obtained and generally collected in a pseudo-random  
127 manner on a grounded collector (Lukáš et al., 2009). The stability of the polymer jet and the related fiber  
128 morphology depend on the spinning system properties, processing parameters and environmental conditions  
129 (Amiraliyan et al., 2009; Ismail et al., 2017; Thompson et al., 2007). In this sense, electrospinning represents  
130 an easy, versatile, and industrially scalable approach to prepare fibers with tailored properties (Kannan et al.,  
131 2016; J. Xue et al., 2019; M. Yu et al., 2017).

132 During the past decades, both synthetic and naturally derived polymers have been electrospun. Synthetic  
133 polymers are usually easier to electrospun and allow good reproducibility and superior mechanical  
134 performances. Additionally, by using hydrophobic materials, water-resistant mats able to maintain their  
135 peculiar structure in contact with aqueous media can be easily obtained without the need for post-production  
136 treatments. However, such materials usually require the use of organic hazardous solvents to be processed  
137 thereby representing a substantial environmental and health threat. Conversely, the electrospinning of  
138 naturally occurring polymers is starting to be broadly investigated as a less impacting and “greener”  
139 alternative. Indeed, besides the fact that they can be processed via eco-friendly solvents (e.g., water, slightly  
140 acid mixtures, etc), natural biopolymers can be often extracted from food and agricultural wastes hence  
141 endowing the interesting possibility to develop circular economy products (Ding et al., 2019; Kakoria &  
142 Sinha-Ray, 2018; Mendes et al., 2017; Noruzi, 2016; Schiffman & Schauer, 2008). Moreover, such materials  
143 are usually biocompatible, weakly immunogenic, biodegradable, and digestible, and present other peculiar  
144 properties that make them extremely promising for the fabrication of biomedical and pharmaceutical  
145 products, as well as for food packaging and biosensor applications (Dodero, Lova, Vicini, Castellano, et al.,  
146 2020; Galiano et al., 2018). Nevertheless, natural polymers present drawbacks such as poor reproducibility,  
147 mechanical properties and thermal resistance, and usually require a post-processing crosslinking reaction to  
148 exhibit appropriate stability and performances. Hence, it is not surprising that the electrospinning of such  
149 materials is considerably harder compared to synthetic polymers (Valencia et al., 2019; Yi et al., 2020).

150 With these premises, it is not surprising that electrospinning is nowadays widely used to prepare nanofibrous  
151 membranes for a broad range of purposes. For example, electrospun mats find several uses as biomedical and  
152 pharmaceutical devices (Cheng et al., 2018; Miguel et al., 2018), in filter materials (D. Lv et al., 2018;  
153 Snowdon & Liang, 2020), in the packaging sector (Senthil Muthu Kumar et al., 2019; C. Zhang et al., 2020),

154 but also for energy-related applications (J. Wang et al., 2020), sensors and biosensors (Han et al., 2019;  
155 Rozemarie Manea & Berteau, 2019), and textile products (Mirjalili & Zohoori, 2016). Additionally,  
156 electrospinning has proved to be a promising encapsulation technique with several advantages compared to  
157 the common industrial approaches, such as spray-drying and solvent evaporation (Becerril et al., 2020; Celli  
158 et al., 2015; Lohith Kumar & Sarkar, 2018; Shishir et al., 2018). Specifically, apart from its versatility, the  
159 key advantage of electrospinning as an encapsulation technique consists of the absence of heat, which is  
160 fundamental to preserve the structure and properties of the entrapped molecules. However, most of the drugs  
161 and bioactive compounds of major interest are characterized either by low water solubility, poor thermal  
162 stability or a highly volatile nature. Hence, to overcome such limitations and improve the efficiency of  
163 electrospinning as an encapsulation technique, the use of cyclodextrins to obtain functionalized nanofibers  
164 has recently gained increasing relevance.

165

#### 166 **4 Polymer-free Electrospun Cyclodextrin – based Membranes**

167 One of the main requirements to obtain defect-free homogenous nanofibers via electrospinning technique is  
168 the presence of sufficient intermolecular interactions in the working solutions (or melts). In polymer-based  
169 systems, these are usually provided by chain entanglement (Mendes et al., 2017; C. Wang et al., 2016). On  
170 the contrary, the electrospinning of low molecular weight molecules is quite a challenge because of the  
171 complete lack of entanglements. Hence, only a few can be electrospun alone. Among others, owing to their  
172 unique self-assembling behaviour, pure phospholipids (McKee et al., 2006), surfactants (Cashion et al.,  
173 2010), tannic acid (Allais et al., 2018), and cyclodextrins (Celebioglu & Uyar, 2010) can be used to prepare  
174 polymer-free nanofibers. In this sense, thanks to their unique physical-chemical properties, polymer-free  
175 cyclodextrin nanofibers have gained huge interest in recent years. However, their proficient usage in  
176 industrial applications remains a challenge and further studies are required to obtain products with effective  
177 large-scale applicability (Costoya et al., 2017; Topuz & Uyar, 2019, 2020). In the following, a detailed  
178 summary (see Table 1) of the current state-of-the-art is provided by reviewing both proofs of concept and  
179 applicative reports.

180 **Table 1.** Comprehensive summary of polymer-free cyclodextrin electrospun membranes and their main applications. If not indicated (---), the used solvent is only water.

Application	Cyclodextrin	Encapsulated compounds	Solvent	Ref.
Fundamental studies	MβCDs	---	Water, DMF, DMAc, Urea	(Celebioglu & Uyar, 2010, 2012)
	HPβCDs	---	Water, DMF, Urea	(Manasco et al., 2012; W. Zhang et al., 2012)
	HPγCDs	---	Water, DMF, DMAc, Urea	(Celebioglu & Uyar, 2012)
	αCDs	---	Water, DMF, DMAc, DMSO, water – NaOH	(Celebioglu & Uyar, 2013a)
	βCDs	---	Water, DMF, DMAc, DMSO, water – NaOH, ionic liquids	(Ahn et al., 2013; Celebioglu & Uyar, 2013a)
	HPαCDs	---	Water, tap water, salty water	(Celebioglu & Uyar, 2020b)
Drug and bioactive compound delivery systems	HPβCDs	Triclosan	---	(Celebioglu, Umu, et al., 2014; Celebioglu & Uyar, 2011)
		Azobenzene	---	(M. Chen et al., 2013)
		Geraniol	---	(Aytac, Yildiz, Kayaci-Senirmak, San Keskin, Tekinay, et al., 2016)
		Camphor	---	(Celebioglu, Aytac, et al., 2018)
	HPγCDs	Triclosan	---	(Celebioglu, Umu, et al., 2014; Celebioglu & Uyar, 2011)
		Geraniol	---	(Aytac, Yildiz, Kayaci-Senirmak, San Keskin, Tekinay, et al., 2016)
		Camphor	---	(Celebioglu, Aytac, et al., 2018)
	MβCDs	Geraniol	---	(Aytac, Yildiz, Kayaci-Senirmak, San Keskin, Tekinay, et al., 2016)
Fast-dissolving nanofibers for the rapid compound administration	HPβCDs	Spironolactone	EtOH	(Vigh et al., 2013)
		Diclofenac	EtOH	(Balogh et al., 2015)

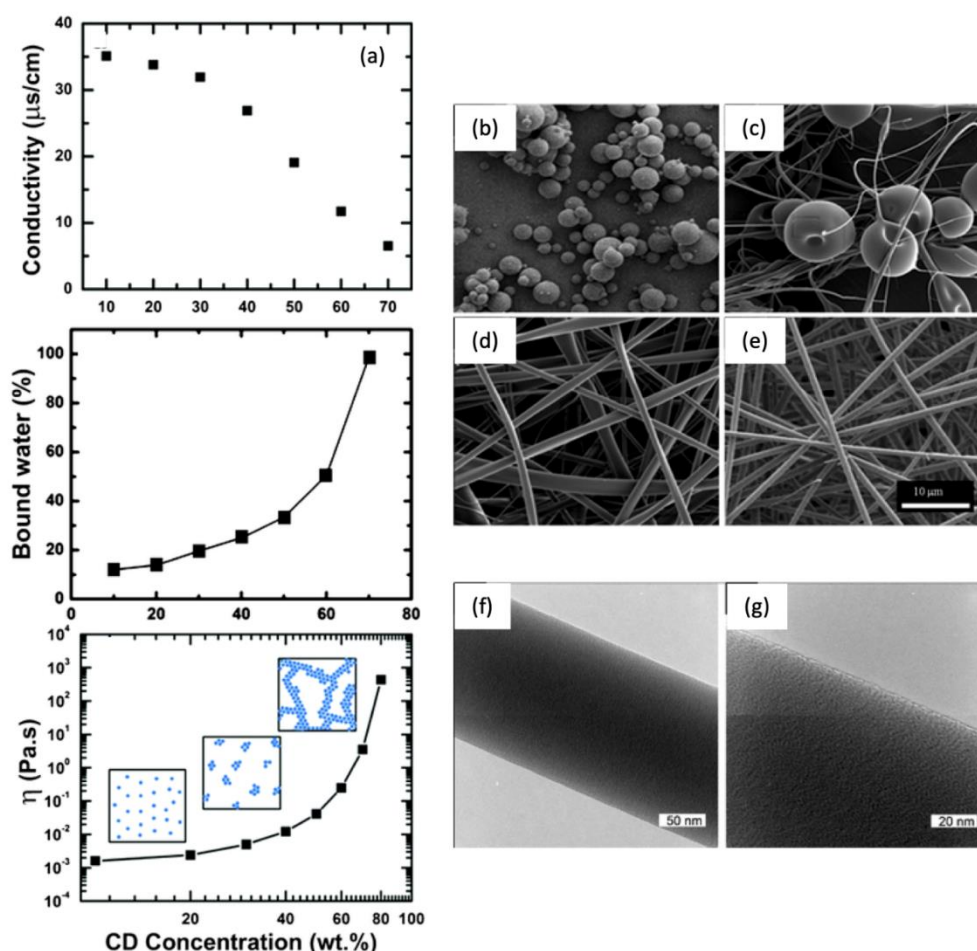
sodium		
Vitamin E	Water – EtOH	(Celebioglu & Uyar, 2017)
Paracetamol	---	(Zehra Irem Yildiz & Uyar, 2019)
$\alpha$ -lipoic acid	---	(Celebioglu & Uyar, 2019a)
Ibuprofen	---	(Celebioglu & Uyar, 2019b)
Metronidazole	---	(Celebioglu & Uyar, 2019c)
Curcumin	---	(Celebioglu & Uyar, 2020c)
Hydrocortisone	---	(Celebioglu & Uyar, 2020d)
Ferulic acid	---	(Celebioglu & Uyar, 2020e)
$\beta$ -galactosidase	---	(Vass et al., 2020)
Doxycycline	---	(Kiss et al., 2020)
Thiabendazole	---	(Gao et al., 2020)
Vitamin-A acetate	---	(Celebioglu & Uyar, 2020a)
Vanillin	Water, DMF, DMAc	(Celebioglu, Kayaci-Senirmak, et al., 2016)
Limonene	---	(Aytac, Yildiz, Kayaci-Senirmak, San Keskin, Kusku, et al., 2016)
Linalool	---	(Aytac, Yildiz, et al., 2017)
Citral	---	(Aytac, Celebioglu, et al., 2018)
Carvacrol	---	(Zehra I. Yildiz et al., 2018)
Menthol	---	(Zehra Irem Yildiz et al., 2018)
Cineole	---	(Celebioglu, Yildiz, et al., 2018a)
p-cymene	---	(Celebioglu, Yildiz, et al., 2018a)
Eugenol	---	(Celebioglu, Yildiz, et al., 2018b)
Thymol	---	(Celebioglu, Yildiz, et al., 2018c)
Cinnamaldehyde	---	(Zehra I. Yildiz et al., 2019)
Living bacteria	Water – skim milk	(San Keskin et al., 2018)

SEB $\beta$ CDs	Acyclovir	---	(Celebioglu & Uyar, 2021)
	Kanamycin	---	(Topuz et al., 2021)
	Chloramphenicol	---	(Topuz et al., 2021)
	Gentamicin	---	(Topuz et al., 2021)
	Ampicillin	---	(Topuz et al., 2021)
	Sulfisoxazole	---	(Zehra Irem Yildiz et al., 2017)
	Paracetamol	---	(Zehra Irem Yildiz & Uyar, 2019)
	Voriconazole	---	(Vass et al., 2019)
	$\alpha$ -lipoic acid	---	(Celebioglu & Uyar, 2019a)
	Curcumin	---	(Celebioglu & Uyar, 2020c)
HP $\gamma$ CDs	Ferulic acid	---	(Celebioglu & Uyar, 2020e)
	Vanillin	Water, DMF, DMAc	(Celebioglu, Yildiz, et al., 2018b)
	Limonene	---	(Aytac, Yildiz, Kayaci-Senirmak, San Keskin, Kusu, et al., 2016)
	Linalool	---	(Aytac, Yildiz, et al., 2017)
	Citral	---	(Aytac, Celebioglu, et al., 2018)
	Carvacrol	---	(Zehra I. Yildiz et al., 2018)
	Menthol	---	(Zehra Irem Yildiz et al., 2018)
	Cineole	---	(Celebioglu, Yildiz, et al., 2018a)
	p-cymene	---	(Celebioglu, Yildiz, et al., 2018a)
	Eugenol	---	(Celebioglu, Yildiz, et al., 2018b)
	Thymol	---	(Celebioglu, Yildiz, et al., 2018c)
	Cinnamaldehyde	---	(Zehra I. Yildiz et al., 2019)
	Vitamin-A acetate	---	(Celebioglu & Uyar, 2020a)
	Vanillin	Water, DMF, DMAc	(Celebioglu, Kayaci-Senirmak, et al., 2016)
M $\beta$ CDs	Limonene	---	(Aytac, Yildiz, Kayaci-Senirmak, San Keskin,

				Kusku, et al., 2016)
				(Aytac, Yildiz, et al., 2017)
				(Aytac, Celebioglu, et al., 2018)
				(Celebioglu, Yildiz, et al., 2018b)
				(Celebioglu, Yildiz, et al., 2018c)
Air filter materials	$\gamma$ CDs	---	Water – DMSO	(Celebioglu & Uyar, 2013b)
	HP $\beta$ CDs	---	Water – DMF	(Celebioglu, Sen, et al., 2016)
	HP $\gamma$ CDs	---	Water – DMF	(Celebioglu, Sen, et al., 2016)
Reducing agents for nanoparticle synthesis	HP $\beta$ CDs	Au-NPs	Water – DMF	(Celebioglu & Uyar, 2013c)
		Ag-NPs	Water – DMF	(Celebioglu, Topuz, Yildiz, et al., 2019b)
		Pd-NPs	Water – DMF	(Celebioglu, Topuz, & Uyar, 2019a)
Sacrificial templates for ceramic hollow nanofibers	HP $\beta$ CDs	---	DMF	(Celebioglu, Vempati, et al., 2014)
	M $\beta$ CDs	---	DMF	(Celebioglu, Vempati, et al., 2014)
Water purification	PolyHP $\beta$ CDs	---	---	(Celebioglu et al., 2017)
		Poly-benzoxazine	DFM	(Dogan et al., 2019)
		---	---	(Celebioglu, Topuz, Yildiz, et al., 2019a)
		---	Water – NaOH	(Celebioglu, Topuz, & Uyar, 2019b)
	Peracetylated $\beta$ CDs	---	DMF	(Topuz et al., 2020)
Implantable scaffolds	PolyHP $\beta$ CDs	Triclosan	---	(Hamsici et al., 2017)
		Azobenzene	Water – NaOH	(Heydari et al., 2018)

## 4.1 Fundamental Studies

The first report concerning polymer-free cyclodextrin electrospun nanofibers can be attributed to the group of Uyar ten years ago, which investigated the electrospinning of methyl- $\beta$ -cyclodextrins using water or dimethylformamide (DMF) as solvents with a concentration ranging from 50 wt% to 61 wt% (i.e., 100-160 w/v%) (Celebioglu & Uyar, 2010). A few years later, the same authors extended their studies to three other CD derivatives (i.e., HP $\beta$ CDs, HP $\gamma$ CDs and M $\beta$ CDs) in different solvents (Celebioglu & Uyar, 2012). Similarly to polymer-based systems, the results revealed that CD electrospinning is mainly governed by the solution viscosity, bound water, and conductivity. Comparable findings were also reported by Manasco et al. (Manasco et al., 2012), who investigated the possibility to prepare HP $\beta$ CD-based nanofibers (Figure 4a-g) by using aqueous solutions with a concentration in the range of 10-70 wt%.



**Figure 4.** (a) Effect of HP $\beta$ CD concentration on the conductivity, bound water and viscosity of aqueous solutions. SEM micrographs of electrospun HP $\beta$ CD solutions of (b) 50 wt%, (c) 60 wt%, (d) 65 wt%, (e) and (f) 70 wt%. TEM micrographs showing fibers electrospun from a 65 wt% solution at (f) 200000X and (g) 400000X magnifications. Reproduced with permission from Manasco et al., 2012. © The Royal Society of Chemistry 2012.

197  
198 In another work, Zhang et al. (W. Zhang et al., 2012) evaluated the influence of HP $\beta$ CD concentration on the  
199 electrospinning process in DMF. By studying the solution viscosity concentration dependence and the  
200 concentration regimes, the authors supposed that HP $\beta$ CDs behave in DMF as neutral polymers in good  
201 solvents nevertheless much higher scaling factors were observed compared to the predicted ones (Colby,  
202 2010). Such results were explained by considering the HP $\beta$ CD tendency to self-aggregate similarly to  
203 wormlike micelles (Cashion et al., 2010; Doderio, Vicini, Alloisio, et al., 2020; Rubinstein & Semenov,  
204 2001). Celebioglu et al. (Celebioglu & Uyar, 2013a) also reported on the electrospinning of native  $\alpha$ CDs and  
205  $\beta$ CDs from aqueous solutions in the concentration range 55-61 wt% (i.e., 120-160 w/v%). As for their  
206 derivatives, the concentration of native cyclodextrin solutions was found to play a fundamental role in  
207 conditioning the nanofiber morphology. Interestingly, besides the fact that native CDs are highly crystalline,  
208 the authors proved that the resultant CD nanofibers were completely amorphous probably due to the fast  
209 solvent evaporation rate. Yet, Ahn et al. (Ahn et al., 2013) presented the preparation of native  $\beta$ CD  
210 nanofibers by using an ionic liquid and DMF as solvents and a concentration between 10 wt% and 60 wt%.  
211 Only recently, Celebioglu et al. (Celebioglu & Uyar, 2020b) investigated the possibility to prepare  
212 nanofibrous membranes by using highly concentrated (i.e., 61-71 wt% or 160-240 w/v%) hydroxypropyl-  
213  $\alpha$ CDs (HP $\alpha$ CDs) solutions. Noticeably, the authors also considered industrially relevant aspects by using  
214 distilled water, tap water and salty water for preparing the nanofibrous membranes. Furthermore, the effect  
215 on the electrospinning process of solution storage over 8 days was investigated due to the tendency of CDs to  
216 form aggregates, despite no significant changes were observed neither in the viscosity of the solutions nor in  
217 terms of electrospun fiber morphology.

218

## 219 **4.2 Applicative Studies**

220 The previously discussed pioneering works demonstrated the possibility to fabricate polymer-free  
221 cyclodextrin nanofibers straightforwardly by using different types of CDs and solvents, thereby anticipating  
222 the development of a broad number of applicative products.

223



#### 224 4.2.1 Drug and Bioactive Compound Delivery Systems with Enhanced Release Performances

225 The ability of CDs to increase the water solubility of several hydrophobic molecules, as well as their thermal  
226 resistance, light stability, and bioavailability, has led to the development of polymer-free nanofibers with  
227 enhanced drug delivery capabilities hence allowing the development of a new generation of biomedical and  
228 pharmaceutical devices.

#### 230 Encapsulation of Hydrophobic Drugs

231 Celebioglu et al. (Celebioglu, Umu, et al., 2014; Celebioglu & Uyar, 2011) first prepared HP $\beta$ CD-ICs-  
232 triclosan and HP $\gamma$ CD-ICs-triclosan (TCL) electrospun membranes via the electrospinning of polymer-free  
233 aqueous solutions achieving defect-free homogeneous nanofibers, with similar morphological results  
234 obtained with poly(lactic acid)-based nanofibers in the work of Kayaci et al. (Kayaci, Umu, et al., 2013). The  
235 authors investigated the CD-ICs-TCL formation to select the optimal compound concentration to obtain  
236 homogeneous nanofibers while avoiding the presence of free triclosan molecules. Both HP $\beta$ CD-ICs-TCL  
237 and HP $\gamma$ CD-ICs-TCL nanofibers were tested against E. Coli and S. Aureus bacteria showing enhanced and  
238 prolonged antibacterial properties compared to uncomplexed triclosan powder. Remarkably, Chen et al. (M.  
239 Chen et al., 2013) reported on the preparation of UV-responsive nanofibers consisting of the inclusion  
240 complexes between HP $\beta$ CDs and azobenzene (AAB) molecules. By investigating the effect of UV light in  
241 different phases of the electrospinning process, the authors were able to prove the responsive properties of  
242 the prepared mats which were pointed out to be extremely promising for the development of stimuli-  
243 controlled drug delivery systems.

#### 245 Encapsulation of Volatile Bioactive Substances

246 Polymer-free cyclodextrin nanofibers can also be efficiently exploited to avoid the rapid evaporation of  
247 highly volatile compounds. For example, Aytac et al. (Aytac, Yildiz, Kayaci-Senirmak, San Keskin, Tekinay,  
248 et al., 2016) prepared HP $\beta$ CD, HP $\gamma$ CD, or M $\beta$ CD geraniol inclusion complex nanofibrous mats. The authors  
249 proved the capability to encapsulate a higher amount of geraniol in pure CD nanofibers (~11 wt%) compared  
250 to polymeric membranes (~5 wt%). After both short-term temperature and long-term open-air release studies,

251 M $\beta$ CD-based nanofibers showed the slowest release of geraniol. Moreover, along with strong antibacterial  
252 activities, CD-ICs-geraniol mats also displayed efficient antioxidant properties. Yet, Celebioglu et al.  
253 (Celebioglu, Aytac, et al., 2018) prepared HP $\beta$ CD-ICs- and HP $\gamma$ CD-ICs-camphor nanofibers from highly  
254 concentrated aqueous solutions obtaining thermally stable and manageable membranes, with HP $\gamma$ CD-ICs-  
255 camphor nanofibers showing a slow release of the compound.

256

#### 257 4.2.2 *Fast-dissolving Nanofibers for the Rapid Compound Administration in Food or Pharmaceutical* 258 *Products*

259 Polymer-free cyclodextrin nanofibers are highly soluble in water if not subjected to a crosslinking reaction  
260 (see Section 5), but such drawback has been efficiently turned into a benefit by exploiting the fast-dissolving  
261 nature of these systems for the rapid administration of drugs and bioactive compounds in both food and  
262 pharmaceutical products (Balusamy et al., 2020). Owing to their capability to form stable inclusion  
263 complexes, cyclodextrins can indeed considerably increase the water-solubility of a wide variety of guest  
264 hydrophobic drugs and volatile molecules that can consequently be rapidly released when in contact with a  
265 high moisture environment, human saliva or biological fluids (Cheirsilp & Rakmai, 2017; Mura, 2015).

266

#### 267 *Encapsulation for the Fast-dissolution of Hydrophobic Substances*

268 The encapsulation of a hydrophobic drug within polymer-free cyclodextrin membranes has been first  
269 demonstrated by Vigh et al. (Vigh et al., 2013). The authors reported on polymer-free HP $\beta$ CD nanofibers  
270 encapsulating spironolactone which were able to completely release the encapsulated drug within a minute,  
271 therefore being promising for the rapid oral administration of highly lipophilic compounds. Shortly after,  
272 Balogh et al. (Balogh et al., 2015) investigated the possibility to prepare fast-dissolving HP $\beta$ CD nanofibers  
273 containing diclofenac sodium (DCF), a poorly soluble and highly crystalline drug, to avoid the common  
274 issues related to its injection delivery methods. Remarkably, the authors implemented the common  
275 electrospinning set-up with high-speed blowing air (i.e., electroblowing) able to enhance both productivity  
276 rate and fiber morphology. Above all, HP $\beta$ CD-ICs-DCF nanofibers were completely amorphous and  
277 displayed a high solubility in water hence representing a promising alternative to reconstitution injections.

Starting from these preliminary studies, great efforts have been done in preparing fast-dissolving cyclodextrin electrospun nanofibers encapsulating a variety of hydrophobic molecules. For instance, Celebioglu et al. (Celebioglu & Uyar, 2017) reported on the electrospinning of HP $\beta$ CD inclusion complexes with vitamin E, which consists of a long hydrophobic chain. The authors were able to load and preserve around the 13 wt% of vitamin E in the prepared mats observing only a small loss of the compound during the electrospinning process. The mats showed a fast-dissolving nature and strong antioxidant activities, which were even maintained after UV-irradiation and 3-year storage proving the stability of the formed complexes. Relatedly, Yildiz et al. (Zehra Irem Yildiz et al., 2017) developed first a nanofibrous solid inclusion complex between sulfobutylether- $\beta$ -cyclodextrins (SEB $\beta$ CDs) and sulfisoxazole, and then HP $\beta$ CD-ICs- and SBE $\beta$ CD-ICs-paracetamol nanofibrous membranes (Zehra Irem Yildiz & Uyar, 2019). The authors demonstrated that the crystalline nature of paracetamol was completely lost owing to the complexation with CDs, thus increasing its water solubility, bioavailability and thermal stability. Recently, Celebioglu et al. (Celebioglu & Uyar, 2019a, 2019b, 2019c, 2020c, 2020d, 2020e) reported on several types of polymer-free cyclodextrin nanofibers encapsulating hydrophobic drugs showing a fast-dissolving nature. For example, the authors demonstrated the possibility to form stable HP $\beta$ CD-ICs- and HP $\gamma$ CD-ICs- $\alpha$ -lipoic acid nanofibrous membranes. Owing to the absence of crystallinity, the prepared mats displayed a fast-dissolving nature both in water and artificial saliva, and they were characterized by good mechanical resistance. Similarly, the authors prepared free-standing and flexible HP $\beta$ CD-ICs-ibuprofen nanofibers achieving the complete inclusion of the drug within the host molecules and a much higher loading concentration compared to PVA/CD-ICs-ibuprofen nanofibers investigated in the same work. Again, metronidazole, a poorly water-soluble drug widely used in pharmaceutical formulations, was encapsulated in polymer-free HP $\beta$ CD nanofibers via the electrospinning of highly concentrated aqueous solutions. Lately, the authors also reported on the preparation of nanofibrous membranes consisting of the inclusion complex between HP $\beta$ CDs or HP $\gamma$ CDs and curcumin with a remarkable 100% encapsulation efficiency. Specifically, HP $\gamma$ CD-ICs-curcumin nanofibers displayed a much higher water solubility and were almost instantaneously dissolved once in contact with water or artificial saliva. Moreover, the authors were able to prove the enhanced antioxidant properties of the prepared mats compared to pristine curcumin, with similar results reported by

305 Aytac et al. (Aytac & Uyar, 2017). In an analogous study, the authors prepared electrospun HP $\beta$ CD-ICs-  
306 hydrocortisone nanofibers to enhance the water solubility and the bioavailability of the drug obtaining self-  
307 standing and flexible defect-free mats able to completely preserve the drug during the electrospinning  
308 process. Additionally, the authors investigated the preparation of nanofibrous mats consisting of the  
309 inclusion complex between ferulic acid (FA) and HP $\beta$ CDs or HP $\gamma$ CDs. Despite both systems allowed to  
310 reach a compound content of ~11 wt%, HP $\gamma$ CD-ICs-ferulic acid were found to be much more stable thereby  
311 making it possible to obtain amorphous nanofibers with enhanced thermal stability and fast-dissolving nature.  
312 Lately, Gao et al. (Gao et al., 2020) prepared HP $\beta$ CD-ICs-thiabendazole (TBZ) nanofibrous mats to exploit  
313 the compound antifungal properties, which are usually limited by its poor solubility. Interestingly, owing to  
314 the fast-dissolving nature of the mats, the antifungal properties of the compound were considerably enhanced  
315 thereby indicating the possibility to use such systems as a novel pesticide formulation. Yet, Celebioglu et al.  
316 (Celebioglu & Uyar, 2020a) demonstrated the possibility to prepare HP $\beta$ CD-ICs- and HP $\gamma$ CD-ICs-vitamin A  
317 acetate nanofibers with self-standing and fast-dissolving nature. In detail, the nanofibers were prepared with  
318 a loading concentration of around 5 wt% with the complexation between the HPCDs and the bioactive  
319 compound ensuring the fast dissolution both in water and artificial saliva media. Only recently, Celebioglu et  
320 al. (Celebioglu & Uyar, 2021) also reported on polymer-free HP $\beta$ CD-ICs-acyclovir nanofibers. In particular,  
321 by using PVP-acyclovir nanofibrous mats as a control sample, the authors proved the greater encapsulation  
322 efficiency of the hydrophobic compound within the membranes in the presence of the inclusion complexes.  
323 Additionally, Topuz et al. (Topuz et al., 2021) also developed polymer-free HP $\beta$ CD nanofibers with high  
324 antibiotic loadings through the electrospinning of cyclodextrin-antibiotic inclusion complexes from water,  
325 and the resultant fast-dissolving fibers demonstrated high antibacterial activity towards Gram-negative  
326 bacteria.

327 Remarkably, the possibility to prepare polymer-free cyclodextrin nanofibers at an industrial scale has also  
328 been explored, despite only a few works are reported in the literature. In this regard, Vass et al. (Vass et al.,  
329 2019) investigated the use of a high-speed electrospinning (HSES) setup to process an aqueous solution of  
330 SBE $\beta$ CD-ICs-voriconazole (VOR). The authors were able to achieve an outstanding production rate of 300  
331 mL/h (i.e., 240 g/h of solid material) under ambient conditions and the grounded fibrous powder showed to

332 be rapidly dissolvable in water with similar results to Vfend® (i.e., reference commercial pharmaceutical  
333 product containing VOR), consequently demonstrating the capability of the proposed approach to fulfil the  
334 requirements of the pharmaceutical industry. More recently, the authors also reported on the high-speed  
335 electrospinning of HPβCD nanofibers containing β-galactosidase, which is a protein-type drug widely used  
336 in pharmaceutical formulations, that were subsequently grounded and converted in tablets for oral  
337 assumption with β-galactosidase found to maintain its activity over a period of 6 months (Vass et al., 2020).  
338 Similarly, Kiss et al. (Kiss et al., 2020) developed a solid HPβCD-ICs-doxycycline (DOX) intravenous  
339 formulation using high-speed electrospinning with a production rate of ~80 g/h (i.e., solid material). The  
340 authors proved that the explored inclusion complex allowed the preparation of a DOX formulation with a  
341 concentration 7 times higher than the commercially available ones, hence suggesting HSES as an alternative  
342 to freeze-drying technique.

343

#### 344 *Encapsulation for the Fast-dissolution of Volatile Substances*

345 Another important advantage of polymer-free cyclodextrin nanofibers is their ability to encapsulate highly  
346 volatile compounds hence preserving their bioactivity over a long period while ensuring their fast  
347 administration when required. For example, Celebioglu et al. (Celebioglu, Kayaci-Senirmak, et al., 2016)  
348 prepared polymer-free electrospun mats by using the inclusion complexes between vanillin and HPβCDs,  
349 HPγCDs, and MβCDs in water, DMF or DMA. The authors demonstrated that MβCDs were more stably  
350 linked to vanillin leading to a higher encapsulation efficiency (up to ~12 wt%). Remarkably, compared to  
351 pure PVA and PVA/CD-ICs-vanillin nanofibers (Kayaci & Uyar, 2012b), the proposed CD-based mats could  
352 encapsulate a considerably higher amount of vanillin and showed strong antioxidant activities, high thermal  
353 stability and the possibility to tune their dissolving behaviour. Similarly, Aytac et al. (Aytac, Yildiz, et al.,  
354 2017; Aytac, Yildiz, Kayaci-Senirmak, San Keskin, Kuskü, et al., 2016) proposed the preparation of  
355 polymer-free HPβCD-, HPγCD-, and MβCD-based nanofibrous mats encapsulating the highly volatile  
356 limonene or linalool compounds. In both cases, the authors proved MβCD nanofibers to be the most efficient  
357 in terms of encapsulation capability. Remarkably, short-term (i.e., 3h) and long-term (i.e., 100 days) release  
358 studies demonstrated the stability of the encapsulated compounds within the nanofibrous mats, which

showed strong antibacterial activities against both Gram-positive and Gram-negative bacteria, as well as good manageability and fast-dissolving character in water or high humidity environment. In another study, the authors reported on the encapsulation of citral within HP $\beta$ CD-, HP $\gamma$ CD- and M $\beta$ CD-based nanofibers obtaining an 80% encapsulation efficiency and the capability to preserve half of the volatile compound after 15 days, as well as increasing both its thermal stability and water solubility (Aytac, Celebioglu, et al., 2018). Comparably, fast-dissolving polymer-free HP $\beta$ CD-ICs- and HP $\gamma$ CD-ICs-carvacrol nanofibers with potential applications as food or oral care products were reported by Yildiz et al. (Zehra I. Yildiz et al., 2018). Besides the high encapsulation efficiency, the carvacrol complexation enhanced its thermal stability and antioxidant properties for up to three years. In a similar study, the authors explored the preparation of polymer-free CD-ICs-menthol nanofibers by using highly concentrated HP $\beta$ CD-IC and HP $\gamma$ CD-IC aqueous solutions (Zehra Irem Yildiz et al., 2018). The stable complexation of menthol, a volatile substance with strong antibacterial properties widely used in several applications, led to an increase of the compound solubility and thermal stability while allowing to obtain homogenous and smooth nanofibers with good flexibility and a fast-dissolving character. The developed mats endorsed to encapsulate a much higher amount of menthol, which was also stable over a long period, compared to polystyrene (PS)/CD-ICs-menthol (Uyar, Hacaloglu, et al., 2009) and polymethylmethacrylate (PMMA)/CD-ICs-menthol (Uyar, Nur, et al., 2009) nanofibers. Also, Celebioglu et al. (Celebioglu, Yildiz, et al., 2018a) prepared HP $\beta$ CD-ICs- and HP $\gamma$ CD-ICs-based electrospun mats containing cineole or p-cymene. HP $\gamma$ CD-based nanofibers were able to encapsulate a greater amount of cineole, whereas p-cymene was better preserved by the HP $\beta$ CD-based ones. However, both mats improved the compound thermal stability consequently representing potential products in food and oral care applications. Yet, the authors investigated the preparation of free-standing nanofibrous mats obtained via the electrospinning of HP $\beta$ CD-ICs-, HP $\gamma$ CD-ICs-, and M $\beta$ CD-ICs-eugenol or thymol (THY) systems (Celebioglu, Yildiz, et al., 2018b, 2018c). The complex formation within the nanofibers allowed to reach an encapsulation efficiency considerably higher compared to analogous PVA/CDs-ICs-eugenol nanofibers (Kayaci, Ertas, et al., 2013). Additionally, owing to their fast-dissolving nature, CD-ICs-eugenol and CD-ICs-thymol nanofibers showed much stronger antioxidant properties compared to the pure compounds. In another work, cinnamaldehyde was successfully encapsulated in self-standing HP $\beta$ CD- and HP $\gamma$ CD-based

nanofibers by Yildiz et al. (Zehra I. Yildiz et al., 2019). Bead-free and homogeneous nanofibers were obtained with considerably higher efficiency in preserving the volatile cinnamaldehyde compared to analogous PLA-based nanofibers (Y. Liu et al., 2017). Moreover, owing to their fast-dissolving nature, the prepared mats displayed strong antibacterial properties against E. Coli representing a new potential class of materials for applications in both the food, biomedical and pharmaceutical industries.

#### *Encapsulation of Living Bacteria*

Keskin et al. (San Keskin et al., 2018) demonstrated the possibility to encapsulate living bacteria within electrospun HP $\beta$ CD-based nanofibers to increase their availability for wastewater bioremediation applications. Despite the encapsulation efficiency was not particularly high, a sufficient amount of bacteria was preserved during the preparation process with the cell viability maintained for 7 days. Remarkably, the used bacteria retained their bioactivity and were proved able to remove Ni(II), Cr(VI) and a commercial reactive dye from aqueous solutions. Such findings indicated the proposed approach as a faster and simpler alternative to the lyophilization procedure commonly applied to preserve organisms for strain collections and applications in dye removal products.

#### *4.2.3 Applications in Air and Water Filtration*

The capability of cyclodextrins and their derivatives to form stable non-covalent inclusion complexes with a variety of molecules makes them extremely interesting for the removal of several pollutants from the environment. Furthermore, nanofibrous electrospun membranes represent a class of materials with superior adsorption capabilities owing to their unique structure, which allows exploiting a higher surface of interaction between the adsorbent and the adsorbate. With these premises, in the past decade, intensive research has been carried out to develop efficient filter materials based on polymer-free cyclodextrin nanofibers aiming to maximize the adsorption capability. Celebioglu et al. (Celebioglu & Uyar, 2013b) first reported on the electrospinning of pristine  $\gamma$ CDs in dimethyl sulfoxide (DMSO) aqueous solutions to be used for the entrapment of volatile organic compounds (VOCs). The obtained electrospun mats were completely amorphous and presented, above all, a surface area three times higher than their powder form according to

413 BET analysis. Aniline and toluene volatile organic compounds were used to test the adsorption ability of  
414  $\gamma$ CD nanofibers that showed a marked complexation capability compared to  $\gamma$ CD powder. Similarly, the  
415 authors also investigated the possibility to use HP $\beta$ CD- and HP $\gamma$ CD-based nanofibers as filter materials  
416 (Celebioglu, Sen, et al., 2016). Polymer-free electrospinning of CDs was carried out in water and DMF  
417 obtaining defect-free mats with a considerably higher surface area with respect to CD powders. DMA  
418 characterization was employed to demonstrate the good mechanical properties and integrity of the obtained  
419 mats, which were indicated as potentially foldable materials to be inserted in air filter modules. Recently,  
420 Topuz et al. (Topuz et al., 2020) reported on hydrophobic water-insoluble nanofibers obtained from the  
421 polymer-free electrospinning of peracetylated  $\beta$ -cyclodextrins. Native  $\beta$ CDs were first modified and  
422 subsequently electrospun by using a DMF solution, whose minimum concentration to obtain defect-free  
423 nanofibers was ~64 wt% (i.e., 180 w/v). The peracetylation procedure drastically boosted the thermal  
424 stability and the hydrophobicity of the obtained nanofibers, which were indeed being proved to maintain  
425 their nanofibrous structure in water for 24h.

426

#### 427 4.2.4 Other Applications

428 Despite the capability to form inclusion complexes that remains one of the most interesting and exploited  
429 properties of cyclodextrins, other promising applications have been considered as well. For example, their  
430 use for the easy synthesis of metal nanoparticles have been also investigated (He et al., 2019; Prochowicz et  
431 al., 2016, 2017). CDs can indeed directly act as reducing agents for metal ions without the need for toxic  
432 chemicals or severe processing conditions, hence allowing the development of environmentally benign  
433 materials with unique features and a wide range of possible applications (Celebioglu, Aytac, et al., 2014;  
434 Shan Wang, Bai, Li, & Zhang, 2012; Shan Wang, Bai, Li, Zhang, et al., 2012). Celebioglu et al. (Celebioglu  
435 & Uyar, 2013c) first proposed the one-step in-situ synthesis of gold nanoparticles (Au-NPs) via the  
436 electrospinning of HP $\beta$ CD solutions containing an appropriate salt precursor. The authors exploited the  
437 capability of CDs to act as reducing and stabilizing agents, as well as fibrous matrix supporting material, to  
438 synthesize Au-NPs directly during the electrospinning process. Subsequently, the authors reported on the  
439 preparation of HP $\beta$ CD nanofibers containing in-situ synthesized silver nanoparticles (Ag-NPs) produced by

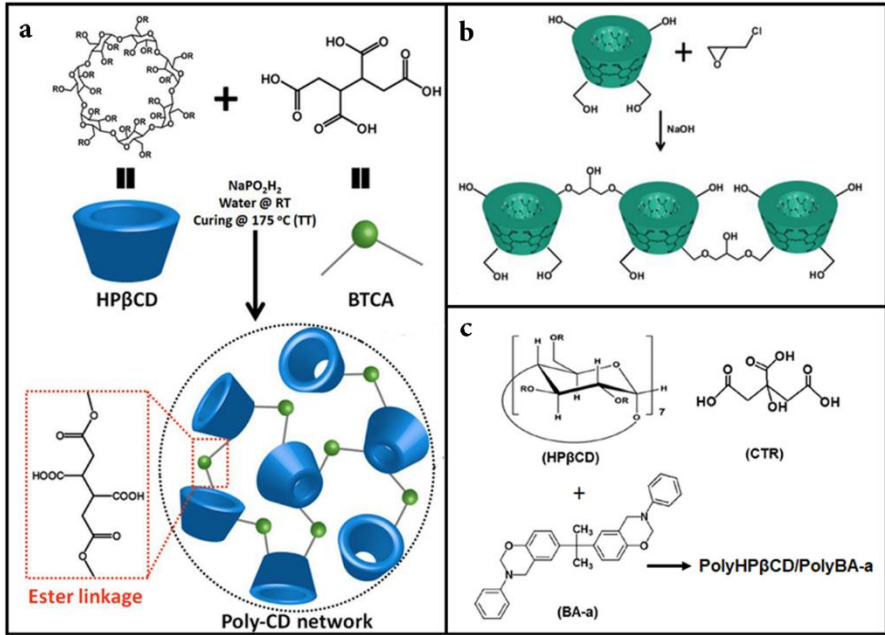


a single-step electrospinning process (Celebioglu, Topuz, Yildiz, et al., 2019b). The authors observed that DMF solution led to thinner nanofibers compared to water, besides an increase of the mean diameter was observed for both solvents by increasing the amount of loaded Ag salt precursor, as similarly reported by Chae et al. (Chae et al., 2011). TEM images revealed that Ag-NPs having a size between 2 and 5 nm were successfully embedded within the nanofibers, with their dimension being a function of the precursor amount and solvent type. Owing to the nanoparticle presence, the prepared nanofibers showed strong antibacterial properties against E. Coli and S. Aureus bacteria over a period of 24h, thus being suitable also for biomedical and food packaging applications. Yet, the authors proposed HP $\beta$ CD nanofibers loaded with palladium nanoparticles (Pd-NPs) (Celebioglu, Topuz, & Uyar, 2019a). Cyclodextrin solutions in water and DMF containing an appropriate precursor were electrospun leading to bead-free nanofibers. Pd-NPs were homogeneously distributed within the nanofibers and showed a dimension ranging from 3 up to 5 nm that increased with the precursor loading concentration and was bigger for DMF compared to water. Moreover, HP $\beta$ CD/Pd-NP nanofibers showed strong catalytic performances being able to reduce p-nitrophenol (PNP) in few minutes into p-aminophenol (PAP), thus showing great potentialities for the development of products for catalytic applications.

Cyclodextrin-based nanofibers, owing to their fast-dissolving character in water, can be even employed as sacrificial templates for the development of hollow nanofibers. To this purpose, Celebioglu et al. (Celebioglu, Vempati, et al., 2014) reported on polymer-free cyclodextrin nanofibers (i.e., HP $\beta$ CDs and M $\beta$ CDs) as a sacrificial pattern for the preparation of metal oxide nanotubes via atomic layer deposition (ALD). The authors proved the possibility to deposit a layer of aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) or zinc oxide (ZnO) on the nanofiber surface to obtain a core-shell structure, subsequently removing the cyclodextrin core by a simple washing process in water. The presence of -OH groups was found to promote the smooth and homogeneous deposition as shown by SEM images, whereas TEM analysis indicated that Al<sub>2</sub>O<sub>3</sub> and ZnO maintained an amorphous and highly crystalline nature with wurtzite structure. Despite such an approach remains at a preliminary stage, the obtained findings indicated that the use of water-soluble CD nanofibers could lead to the simple and cost-effective preparation of metal oxide nanotubes with possible energy storage applications (Yun et al., 2020).

5 Water-insoluble Crosslinked Polycyclodextrin Nanofibers

The high surface area of cyclodextrin-based electrospun mats and their unique inclusion complexation capability make such systems very promising for wastewater purification applications, as well as for implantable biomedical devices. However, as broadly discussed in the previous Section, their high solubility and fast-dissolving features in aqueous environments represent a limitation to their proficient use for such applications. Therefore, the development of crosslinked cyclodextrin-based systems has started to be explored in the viewpoint to fabricate insoluble and highly performing systems. However, as summarized in Table 1, only a few studies are reported in the literature and further research are needed to investigate eventual toxicity issues related to the crosslinking reaction. Figure 5 depicts some of the most commonly employed crosslinking approaches for cyclodextrins.



**Figure 5.** Schematics of different crosslinking strategies of the cyclodextrin nanofibers. The crosslinking agents are added to the CD solution prior to electrospinning and a curing step initiate the reaction in the final membrane. Reaction of CDs with (a) 1,2,3,4-butanetetracarboxylic acid (BTCA) (reproduced with permission from Celebioglu et al., 2017. © The Author(s) 2017), (b) epichlorohydrin (ECH) (reproduced with permission from Celebioglu, Topuz, & Uyar, 2019b. © 2018 American Chemical Society), and (c) citric acid (CTR) and benzoxazine (BA-a) monomers (reproduced with permission from Dogan et al., 2019. © 2019 Elsevier Ltd).

5.1 Water Purification Applications of polyCD Nanofibers

Celebioglu et al. (Celebioglu et al., 2017) first demonstrated the possibility to prepare crosslinked electrospun poly-cyclodextrin nanofibers as highly efficient molecular filter materials. By using

butanetetracarboxylic acid (BTCA) as crosslinker (Figure 5a), the authors avoided the fast dissolution of the prepared polyHP $\beta$ CD nanofibers while maintaining their high hydrophilicity. In particular, polyHP $\beta$ CD nanofibers were characterized by a good affinity with methylene blue (MB) having an extremely high adsorption capacity at dye concentration well above the acceptable limits, showing improved performances compared to an acetate cellulose commercial filter and similar polyacrylonitrile (PAN)/CD nanofibers (W. Zhang et al., 2019). Moreover, the authors were able to prove both their reusability via a simple, fast, and cost-effective washing cycle and their applicability in a real water filtration apparatus. Similarly, Dogan et al. (Dogan et al., 2019) reported on polyHP $\beta$ CD/poly-benzoxazine (polyBA-a) nanofibers as potential dye adsorbents by using citric acid (CTR) as crosslinker and activating the crosslinking reaction via a simple thermal treatment (Figure 5c). The authors proved that the crosslinked mats were able to withstand several washing cycles with both water and organic solvents showing enhanced thermal stability, hence representing promising products for filtration applications. Noticeably, the obtained mats were tested against a mixture of methylene blue and methyl orange (MO) dyes exhibiting a strong selectivity towards MB being able to nearly completely remove the dye in a period of 6h. Yet, Celebioglu et al. (Celebioglu, Topuz, Yildiz, et al., 2019a) evaluated the possibility to use the polyHP $\beta$ CD nanofibers crosslinked with BTCA as filter materials for the removal of several polycyclic aromatic hydrocarbons (PHAs) and heavy metals from water obtaining interesting equilibrium adsorption capabilities and the ability to reduce to half the contaminant amount in only 20 minutes. Interestingly, the proposed mats could be recycled four times by a simple treatment with acetonitrile or with a nitric acid solution without showing changes in their morphology and adsorption capability. Also, the authors recently reported on water-insoluble polyHP $\beta$ CD nanofibers obtained by using epichlorohydrin (ECH) as crosslinker agent (Figure 5b) (Celebioglu, Topuz, & Uyar, 2019b). The rheological investigation of HP $\beta$ CD/ECH aqueous solutions showed that the reaction partially initiated prior to the electrospinning, despite a post-preparation thermal treatment was the main responsible for the process. The obtained polyHP $\beta$ CD nanofibers were proved to be highly hydrophilic, nearly completely amorphous, with enhanced thermal stability, and were above all able to maintain their structure after the immersion in water and several organic solvents. The authors investigated the scavenging ability of the crosslinked nanofibers against phenolphthalein and phenanthrene in their aqueous solutions proving that the prepared

517 nanofibers showed enhanced adsorption capabilities compared to polyHP $\beta$ CD powder and analogous  
518 poly(ethylene terephthalate) (PET)/CD nanofibers (Kayaci, Aytac, et al., 2013).

519

## 520 **5.2 Biomedical Applications of polyCD Nanofibers**

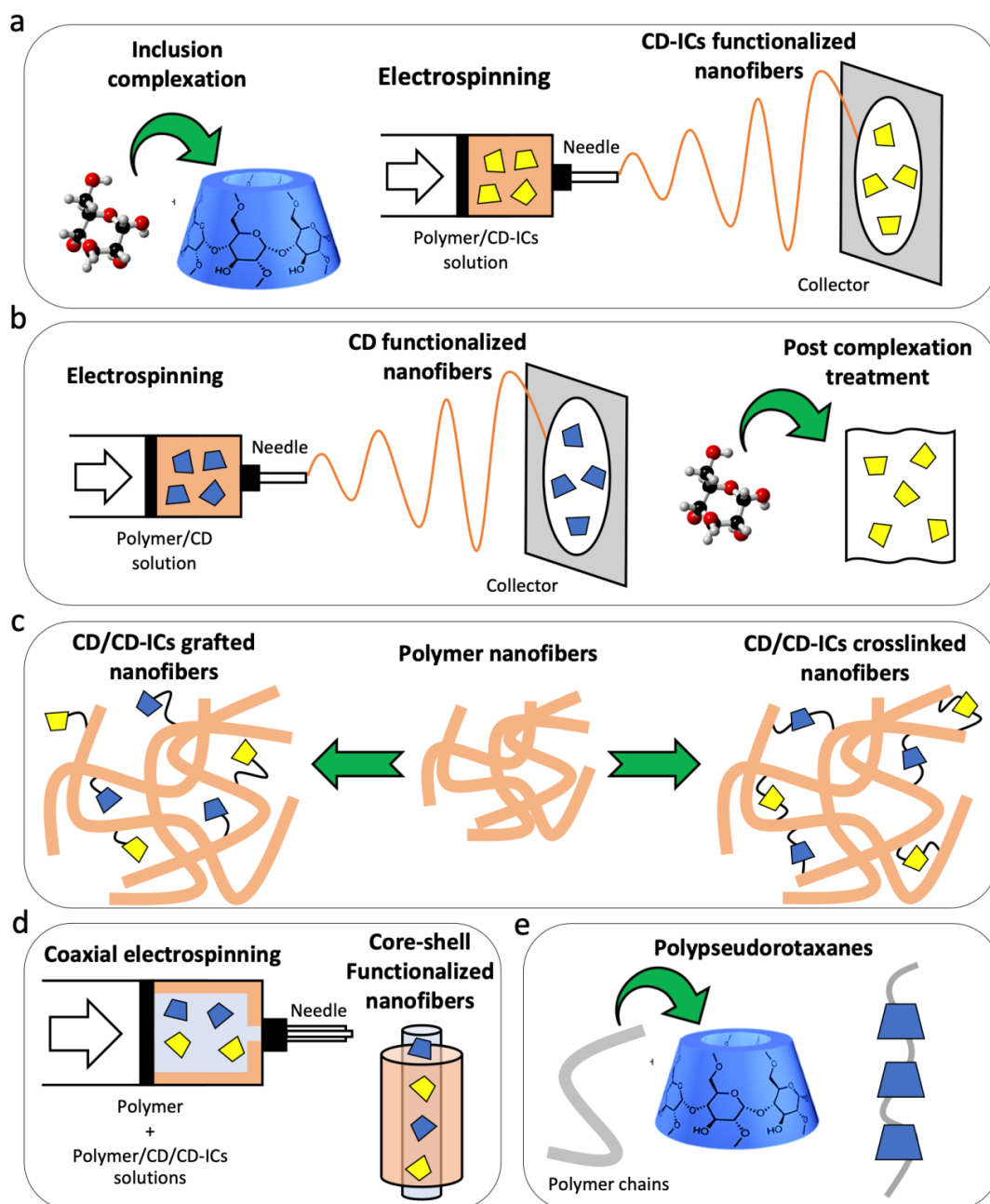
521 Hamsici et al. (Hamsici et al., 2017) proposed water-insoluble HP $\beta$ CD aligned nanofibers functionalized  
522 with bioactive peptides as implantable scaffolds for peripheral nerve regeneration. The highly aligned  
523 nanofibers were first prepared and crosslinked via BTCA before being functionalized with IKVAV or KK  
524 peptides with a simple impregnation procedure. PolyHP $\beta$ CD-ICs-peptide nanofibers did not show toxicity  
525 issues and provided the optimal environment to promote cell adhesion, differentiation and proliferation.  
526 Specifically, the peptide presence on the nanofiber surface was found to guide the differentiation to PC-12  
527 cells compared to unfunctionalized membranes, whereas the aligned topological arrangement was proven to  
528 help the formation of longer neurites compared to the randomly structured samples. In another work, Heydari  
529 et al. (Heydari et al., 2018) prepared hydrophobic peracetyl- $\beta$ CD nanofibers loaded with vitamin B<sub>2</sub> (VB<sub>2</sub>)  
530 by the electrospinning of an acetone/DMF solution. HP $\beta$ CDs were subjected to crosslinking and  
531 peracetylation reactions before being electrospun together with VB<sub>2</sub> leading to bead-free homogeneous  
532 nanofibers. PolyHP $\beta$ CD-ICs-VB<sub>2</sub> nanofiber release kinetic was studied in simulated gastric and intestinal  
533 conditions showing an initial burst release followed by a sustained slow release for 16h. Compared to  
534 HP $\beta$ CD-ICs-VB<sub>2</sub> powder, the prepared mats displayed a considerably slower and more controlled release of  
535 vitamin B<sub>2</sub>, thus representing an important advancement in the development of a new class of controlled drug  
536 delivery systems.

537

## 538 **6 Electrospun Membranes Made of Natural Polymers Functionalized with Cyclodextrins and Their** 539 **Inclusion Complexes**

540 Together with polymer-free CDs and polyCDs nanofibers, electrospun mats containing cyclodextrins have  
541 also been prepared from both native CDs and their derivatives in combination with a broad variety of carrier  
542 polymers able to provide a good spinnability and very specific properties of the mats depending on the  
543 targeted application (Costoya et al., 2017; Topuz & Uyar, 2019). The use of CDs to functionalize nanofibers

544 offers a wide number of advantages and represents a more and more investigated research field owing to the  
545 wide range of possibilities of the obtained products. The ability of CDs to complex hydrophobic compounds  
546 and volatile molecules represents the opportunity to enhance their encapsulation efficiency, stability,  
547 solubility and bioavailability, as well as provide them with controlled release kinetics. For example, such  
548 materials can be used as implantable scaffolds enriched with growth factors and vitamins, pharmaceutical  
549 formulations containing poorly soluble drugs, highly performing filters for wastewater and volatile organic  
550 compounds, and active food packaging materials with antibacterial and antioxidant properties (Alvarez-  
551 Lorenzo et al., 2017; Celebioglu, Sen, et al., 2016; Hall Barrientos et al., 2017; Lin et al., 2017; Moyers-  
552 Montoya et al., 2016; Wen, Zhu, Feng, et al., 2016). Several approaches are reported in the literature to  
553 prepare cyclodextrin-functionalized electrospun nanofibers with some of them schematically illustrated in  
554 Figure 6. The simplest one consists of adding to a proper polymer solution the CDs or the CD-ICs of interest,  
555 with the latter usually prepared by precipitation or freeze-drying methods (Beachley & Wen, 2010; Meinel et  
556 al., 2012). A faster alternative, which is however less applied owing to the difficulty in accurately control the  
557 guest molecule loading concentration, consists of the direct mixing of all the components (i.e., polymer,  
558 cyclodextrins, drug or bioactive compound, etc.) (Narayanan et al., 2017). Another possibility is represented  
559 by the electrospinning of a polymer-cyclodextrins mixture with the a posteriori loading of the guest  
560 molecules of interest usually via a solution impregnation method (Séon-Lutz et al., 2019). Yet, polymer  
561 nanofibers can be functionalized by grafting their surface with CDs or CD-ICs via a chemical reaction,  
562 therefore obtaining a high surface reactivity (Wu et al., 2015; Yuan et al., 2017). Similarly, CDs and their  
563 derivatives can be directly employed as a crosslinker for the polymer chains, thus acting as stabilizing agents  
564 and reducing the nanofiber solubility (Boas et al., 2015; L. Li & Hsieh, 2005). Alternatively, CDs and their  
565 complexes can be completely embedded within the nanofibers by employing a coaxial set-up producing  
566 core-shell nanofibers (Chou et al., 2015). Finally, it should be kept in mind that CDs and CD-ICs, when  
567 mixed with a polymer in a liquid solvent, can thread along the polymer chains forming polypseudorotaxanes.  
568 These can assemble in supramolecular structures where the interactions between CDs play a fundamental  
569 role in conditioning the spinning solution properties (Uyar et al., 2008) and bring grafting sites for nanofiber  
570 post-functionalization (M. Oster et al., 2017; Murielle Oster et al., 2015).



571

572 **Figure 6.** Schematics of preparation methods for cyclodextrin-functionalized nanofibers. (a) Electrospinning  
 573 of polymer/CD-ICs solutions, (b) electrospinning of polymer/CDs/active compound solutions, (c) CD/CD-  
 574 ICs grafted or CD/CD-ICs crosslinked nanofibers, (d) coaxial electrospinning of CD/CD-ICs core  
 575 functionalized nanofibers, and (e) pseudopolyrotaxanes structures.

576

577 To date, both synthetic and natural polymer-based nanofibers have been functionalized with cyclodextrins  
 578 and their derivatives with their advantages and disadvantages. Along with the fact that most natural polymers  
 579 can be processed in green solvents under mild working conditions, their main advantages are enhanced  
 580 biocompatibility, biodegradability and the possibility to be obtained from agricultural and food wastes with  
 581 the development of green and circular economy products. Thereby, it is much likely that natural polymer-

582 based electrospun membranes functionalized with cyclodextrins will soon represent a new class of  
583 environmentally friendly materials with potential applicability in a wide range of markets. In the next two  
584 subsections, the current literature about polysaccharide- and protein-based functionalized electrospun  
585 membranes is critically discussed by highlighting the recent advances.

586

## 587 **6.1 Electrospun Polysaccharide – Cyclodextrin Based Membranes**

588 Polysaccharides are a family of natural polymers consisting of multiple saccharide units linked together  
589 through glycosidic linkages and possess a wide variety of unique properties which make them extremely  
590 interesting from an industrial point of view (Cazón et al., 2017; Dodero, Lova, Vicini, Castellano, et al.,  
591 2020; Y. Yu et al., 2018). Most polysaccharides can be easily and cheaply recovered from natural sources  
592 such as plants, microbes, and animals, with their use being especially profitable when they are by-products of  
593 other processes (Dodero, Vicini, & Castellano, 2020; Hamed et al., 2016; Sila et al., 2014). Compared to  
594 other natural polymers, polysaccharides are usually more stable and not irreversibly denatured upon heating  
595 and can consequently be used as an effective shell to confer enhanced temperature stability to a variety of  
596 bioactive compounds. Moreover, polysaccharides show a broad range of interesting properties such as  
597 biocompatibility, low toxicity, mucoadhesive behaviour, biodegradability, and ease of functionalization,  
598 hence being nowadays widely employed in several industrial fields (Öner et al., 2016). Regardless of their  
599 advantages, the electrospinning of polysaccharides remains a challenge due to their tendency to form strong  
600 hydrogen bonds that lead to high viscous solutions or even gels, the small number of entanglements formed  
601 between the polymer chains, the high solution surface tension, and the poor water stability of the obtained  
602 mats (Dodero, Vicini, et al., 2019; Mendes et al., 2017). For example, Dodero et al. reported on the  
603 preparation of sodium alginate (SA) (Dodero, Alloisio, Vicini, & Castellano, 2020; Dodero, Donati, et al.,  
604 2021; Dodero, Scarfi, Pozzolini, Vicini, et al., 2020) and chitosan (CH) (Dodero, Brunengo, Alloisio,  
605 Sionkowska, et al., 2020; Dodero, Scarfi, et al., 2021) crosslinked electrospun membranes by using  
606 poly(ethylene oxide) (PEO) as a co-spinning agent, which was then removed by a simple post-  
607 electrospinning washing cycle. In another work, Séon-Lutz et al. (Séon-Lutz et al., 2019) proposed the  
608 electrospinning of hyaluronic acid (HA)/PVA solutions being able to decrease the co-spinning agent  
609 concentration compared to other similar works reported in the literature (J. Li et al., 2006), whereas Vicini et

610 al. (Vicini et al., 2018) used a bath collector electrospinning to obtain crosslinked composite  
611 alginate/hyaluronic acid/PEO membranes. Similarly, Ge et al. (Ge et al., 2012) and Huang et al. (X. J. Huang  
612 et al., 2007) reported on chitosan/PVA electrospun membranes for the encapsulation of bioactive compounds,  
613 whereas pullulan (PUL)/PVA nanofibers with UV-resistant properties were obtained by Qian et al. (Qian et  
614 al., 2016). Compared to pure polysaccharide nanofibrous membranes, cyclodextrin-functionalized  
615 polysaccharide nanofibers offer several advantages that will be deeply discussed in this section with a  
616 complete and up-to-date summary of the literature reported in Table 2.

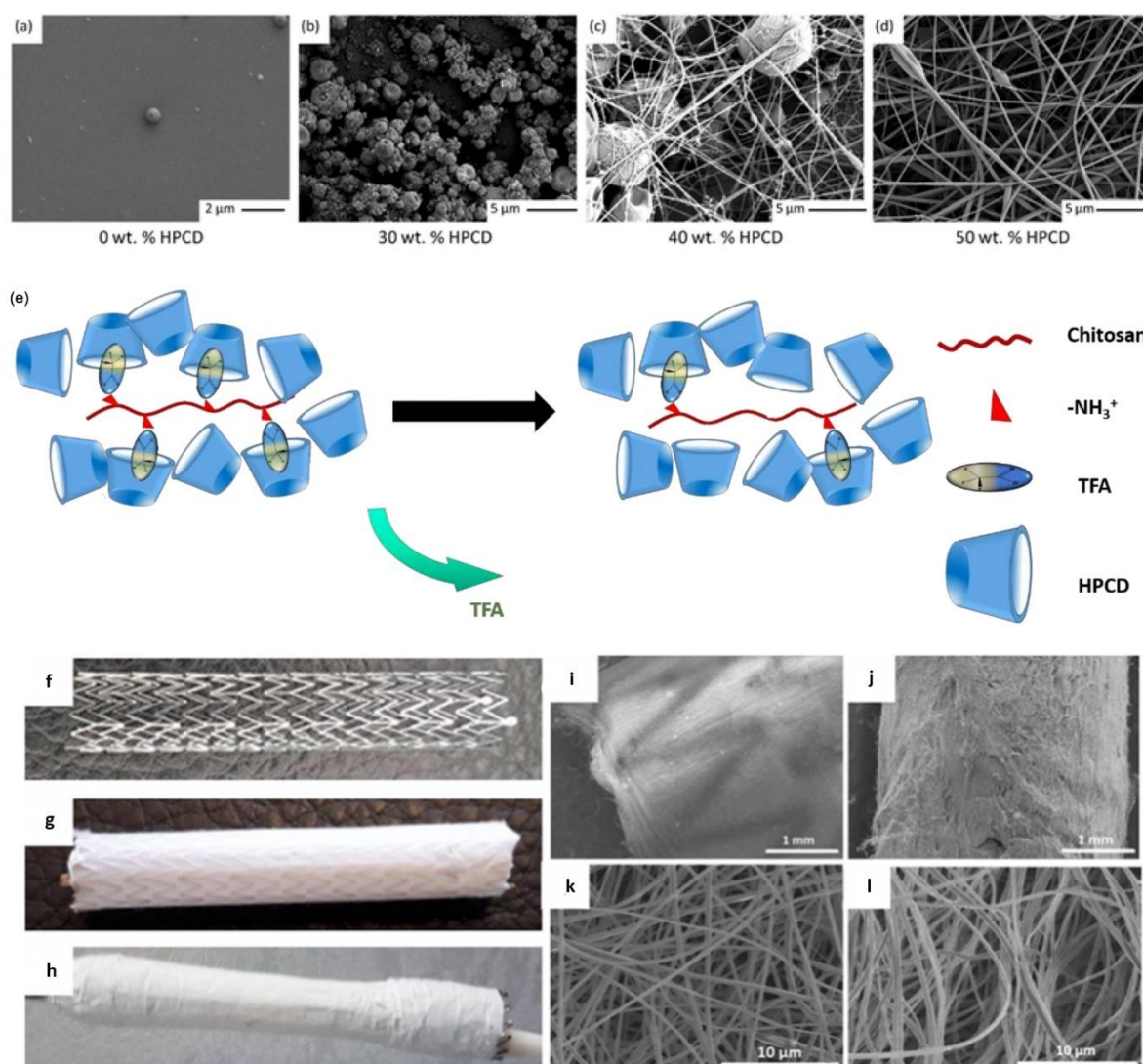


**Table 2.** Comprehensive summary of polysaccharide-based electrospun membranes functionalized with CDs or CD-ICs and their main applications.

Polysaccharide	Cyclodextrins	Encapsulated bioactive molecules	Application	Ref.
Chitosan	$\beta$ CDs	---	Cyclodextrin grafted nanofibers for effluent dye removal	(Norouzi et al., 2012)
		Cinnamon and oregano essential oils	Nanofibrous membranes with strong antibacterial properties for biomedical and food packaging applications	(Munhuweyi et al., 2018)
	CM $\beta$ CDs	Salicylic acid	Cyclodextrin grafted nanofibers as drug delivery systems with tuneable release kinetics	(Bazhban et al., 2013)
	HP $\beta$ CDs	---	Fundamental study of the effect of CDs on chitosan solution spinnability	(Burns et al., 2015; C. Xue & Wilson, 2019)
	Poly-HP $\beta$ CDs	Triclosan	Biomedical and food packaging products with improved water stability, tenable release kinetics and antibacterial properties	(Ouerghemmi et al., 2016)
		Simvastatin	Angioplasty bare metal stent covering layer for restenosis prevention	(Kersani et al., 2020)
Pullulan	$\beta$ CDs	Limonene, Perillaldehyde	Edible food packaging products with antibacterial properties, high stability and humidity triggered release behaviour	(Fuenmayor et al., 2013; Mascheroni et al., 2013)
	$\gamma$ CDs	Eugenol	Biomedical and food packaging products with enhanced release and antioxidant properties	(Celebioglu & Uyar, 2020f)
Cellulose acetate	$\beta$ CDs	N-halamine copolymers	Biomedical and food packaging products with biocidal properties	(R. Li et al., 2014)
		Ag/Fe-NPs	Filter materials embedding in-situ synthesized metal nanoparticles for wastewater purification	(Nthunya et al., 2017)
		---	Odour adsorbent filter materials for oil and fat derived volatile compounds	(Ghorani et al., 2019)
		---	Cyclodextrin grafted nanofibers for the removal of phenanthrene	(Celebioglu, Demirci, et al., 2014)
		---	Cyclodextrin grafted nanofibers as filter materials for toluene in wastewater	(Yuan et al., 2017)
		Tetrafluoroterephthalonitrile	Cyclodextrin grafted nanofibers for the removal of bisphenol pollutants	(Y. Lv et al., 2021)

		Thymol	Porous nanofibers with antibacterial properties and drug delivery capabilities for biomedical applications	(Yajun Chen et al., 2020)
	$\alpha$ CDs	---	Cyclodextrin grafted nanofibers as filter materials for toluene in wastewater	(Yuan et al., 2017)
	$\gamma$ CDs	---	Cyclodextrin grafted nanofibers as filter materials for toluene in wastewater	(Yuan et al., 2017)
<b>Hydroxypropyl cellulose</b>	HP $\beta$ CDs	Sulfisoxazole	Drug delivery systems with enhanced release abilities	(Aytac et al., 2015)
<b>Almond gum</b>	$\beta$ CDs	Curcumin	Drug delivery systems with enhanced encapsulation capabilities for oral and gastrointestinal formulation dosages	(Rezaei & Nasirpour, 2019)
<b>Hyaluronic acid</b>	HP $\beta$ CDs	Naproxen	Wound dressing patches with controlled drug delivery abilities enhanced water-stability	(Séon-Lutz et al., 2019)
<b>Dandelion</b>	$\beta$ CDs	Litsea Cubeba essential oils	Membranes with strong antibacterial properties for biomedical and food packaging purposes	(Cui et al., 2019)

618 *Chitosan* (CH) is a polysaccharide derived from the partial deacetylation of chitin, the second most abundant  
619 biopolymer in nature after cellulose and widely present in the exoskeleton of shellfish and fungi organisms.  
620 Owing to its unique properties and wide availability, chitosan has been recognized as one of the most  
621 promising materials of the future to substitute synthetic polymers (Riaz Rajoka et al., 2019). The first study  
622 concerning chitosan nanofibers functionalized with cyclodextrins can be attributed to Norouzi et al. (Norouzi  
623 et al., 2012) who reported on chitosan/PVA electrospun membranes grafted with  $\beta$ -cyclodextrins for the  
624 efficient dye removal from effluents. After a crosslinking procedure carried out with glutaraldehyde vapours,  
625 the prepared samples were able to retain their nanofibrous structure for a long time during which they  
626 showed a surprisingly high uptake capacity. Similarly, Bazhban et al. (Bazhban et al., 2013) prepared  
627 chitosan/PVA electrospun membranes grafted with carboxymethyl- $\beta$ -cyclodextrins (CM $\beta$ CDs) as drug  
628 delivery systems demonstrating a slower release compared to the correspondent polymer films. Subsequently,  
629 Burns et al. (Burns et al., 2015) tried to understand the effect of HP $\beta$ CDs on the electrospinning process of  
630 chitosan solutions in acetic acid (AA) and trifluoroacetic acid (TFA). The authors observed a strong  
631 improvement in the processability of CH solutions enriched with HP $\beta$ CDs with more homogeneous  
632 nanofibers obtained by increasing the cyclodextrin concentration as shown in Figure 7a-d.



**Figure 7.** Fiber morphology of chitosan-based electrospun mats with an increasing HPβCD content: (a) 0 wt%, (b) 30 wt%, (c) 40 wt%, and (d) 50 wt%. Reproduced with permission from Burns et al., 2015. © The Royal Society of Chemistry 2015. (e) Schematic illustration of CH/HPβCD electrospun nanofiber composition. Reproduced with permission from C. Xue & Wilson, 2019. (f) Macroscopic and microscopic images of Nitinol stent covered with CH/polyHPβCD-ICs-simvastatin nanofibers before (g, i, k) and after crimping (h, j, l). Reproduced with permission from Kersani et al., 2020. © 2020 Elsevier B.V.

Such findings were attributed to the formation of a stable inclusion complex between the hydrophobic cavity of cyclodextrins and chitosan amine groups. More recently, Xue et al. (C. Xue & Wilson, 2019) carried out a solid-state spectroscopic and thermal study on CH/HPβCD electrospun nanofibers obtained using TFA as solvent. On the contrary to what reported by Burns et al. (Burns et al., 2015), it was suggested that the enhanced processability of chitosan solutions was likewise related to the formation of a ternary complex between CH, HPβCDs, and TFA with the solvent molecules acting as bridges, as schematically depicted in Figure 7e. By Raman imaging, the authors were able to prove the absence of direct interactions between

chitosan and cyclodextrins opening the way to the development of new supramolecular structures. Along with these preliminary studies, Ouerghemmi et al. (Ouerghemmi et al., 2016) prepared chitosan electrospun membranes containing the inclusion complexes between polyHP $\beta$ CDs and triclosan. Compared to pristine HP $\beta$ CDs, polyHP $\beta$ CDs provided a higher encapsulation capability and led to the formation of a polyelectrolyte complex with chitosan enhancing the water-resistance to the nanofibers. With respect to chitosan nanofibers functionalized with HP $\beta$ CD-ICs-TCL or free TCL, CH/polyHP $\beta$ CD-ICs-TCL mats showed a slower release over a longer period both at pH = 7.4 and pH = 5.5 conditions. Moreover, the authors proved that the mats were embedded with strong antibacterial activities remarkably higher in terms of growth inhibition zone compared to those of similar synthetic products (Kayaci, Umu, et al., 2013; Tonelli, 2008), thus making them suitable candidates for both biomedical and food packaging applications. Yet, Munhuweyi et al. (Munhuweyi et al., 2018) reported on the encapsulation of cinnamon and oregano essential oils in CH/PVA nanofibers embedding  $\beta$ CDs. Owing to the great encapsulation efficiency, which was much higher compared to PLA-, PVA-, and PCL-based nanofibers containing cinnamon oil (Amiri & Rahimi, 2019; Pan et al., 2019; Wen, Zhu, Feng, et al., 2016; Wen, Zhu, Wu, et al., 2016), the proposed CH/PVA/ $\beta$ CD-ICs-cinnamon mats showed particularly marked antibacterial properties against *Botrytis* sp. bacteria, hence representing interesting materials especially for food packaging applications. Recently, Kersani et al. (Kersani et al., 2020) developed a bare-metal stent for angioplasty covered by an electrospun layer of chitosan/polyHP $\beta$ CD-ICs-simvastatin (SV) drug as an efficient tool for restenosis prevention represented in Figure 7a. Compared to the nanofibers loaded with free SV or embedding HP $\beta$ CD-ICs-SV, the use of polyHP $\beta$ CDs highly improved the drug loading efficiency leading to a much more prolonged and controlled release from the mats. Additionally, the release of simvastatin was found to be tuneable by simply changing the sample thickness or the initial loading concentration indicating the possibility to accurately personalize the system depending on the patient requirements.

*Pullulan* (PUL) is a water-soluble extracellular polysaccharide obtained from fermentation processes and exploited in the manufacturing of edible films, as well as in several biomedical and pharmaceutical oral care applications (Prajapati et al., 2013). In this regard, Fuenmayor et al. (Fuenmayor et al., 2013) developed edible nanofibrous membranes by single-step electrospinning of a pullulan/ $\beta$ CD aqueous solution containing

675 R-(+)-limonene, which was found to be stable over a long time with its release occurring only at high water  
676 activity values ( $a_w$ ) hence making the prepared mats suitable for fresh food packaging products. Similarly,  
677 Mascheroni et al. (Mascheroni et al., 2013) investigated the encapsulation of the volatile compound  
678 perillaldehyde, an aroma largely employed in the food industry, within a pullulan electrospun matrix  
679 containing  $\beta$ CDs. No evident losses of the aroma compound were observed over several months at ambient  
680 conditions with the release occurring exclusively for  $a_w > 0.9$ . Lately, Celebioglu et al. (Celebioglu & Uyar,  
681 2020f) reported on pullulan nanofibers embedding  $\gamma$ CD-ICs-eugenol able to almost preserve the volatile  
682 compound with an encapsulation efficiency of  $\sim 93\%$ , which was considerably higher with respect to  
683 pullulan/eugenol nanofibers (i.e.,  $\sim 23\%$ ). Moreover, the complexation increased the thermal stability of  
684 eugenol, whereas its antioxidant properties were substantially enhanced and remained unvaried over a period  
685 of 3 months.

686 *Cellulose acetate* (CA) is one of the most important derivatives of cellulose and it is widely employed as a  
687 film base for photography, vapour sensors, optical materials, and to produce synthetic fibers for textile  
688 applications owing to its renewable source, biodegradability, non-toxicity and low cost (Candido &  
689 Gonçalves, 2016; Lova et al., 2018, 2019; Ummartyotin & Manuspiya, 2015). Li et al. (R. Li et al., 2014)  
690 prepared CA nanofibrous membranes embedding  $\beta$ CD inclusion complexes with an ad hoc synthesized N-  
691 halamine copolymer as promising candidates for biomedical and food packaging applications with strong  
692 biocidal properties against both Gram-positive and Gram-negative bacteria. Aiming to the efficient removal  
693 of bacteria from drinking water, Nthunya et al. (Nthunya et al., 2017) investigated the possibility to prepare  
694 cellulose acetate/ $\beta$ -cyclodextrin membranes embedding in-situ synthesized metal nanoparticles. Ag/Fe  
695 nanoparticles were here prepared via a green UV photoreduction process under ambient conditions and  
696 enriched the mats with strong antibacterial properties against several bacteria strains thus making them a  
697 valid alternative for water purification purposes. More recently, Ghorani et al. (Ghorani et al., 2019)  
698 developed CA nanofibers embedding  $\beta$ CDs as odour adsorbent filter materials by selecting acetone:DMF  
699 (2:1) as the most appropriate solvent system to obtain a considerably high production rate suitable for  
700 industrial applications. Above all, the proficiency of the prepared mats to adsorb hexanal molecules, which  
701 are a marker for oil and fat oxidation, suggested their suitability for filtration purposes. While the previously  
702 mentioned works consist in the direct electrospinning of CA/CD solutions, a different approach was first

703 proposed by Celebioglu et al. (Celebioglu, Demirci, et al., 2014) who reported on cellulose acetate  
704 nanofibers grafted with  $\beta$ CDs via a simple “click” reaction carried out to avoid leaking issues. The grafted  
705 membranes were tested as potential molecular filters for water purification purposes showing greater  
706 adsorption capability in removing phenanthrene compared to the pristine CA nanofibers, as well as respect to  
707 comparable PET/CD nanofibers (Kayaci, Aytac, et al., 2013). Similarly, Yuan et al. (Yuan et al., 2017)  
708 investigated the possibility to use regenerated cellulose (RC) nanofibers functionalized with  $\alpha$ CDs,  $\beta$ CDs  
709 or  $\gamma$ CDs via physical mixing or grafting reaction for the removal of toluene residues from wastewater. Each  
710 type of CD led to homogenous nanofibers with the grafting approach enriching the mats with considerably  
711 higher adsorption capability compared to the works of Kayaci et al. (Kayaci et al., 2015) and Uyar et al.  
712 (Uyar et al., 2010). Yet, Chen et al. (Yajun Chen et al., 2020) reported on the development of hierarchical  
713 CA nanofibers embedding the inclusion complex between  $\beta$ CDs and thymol. The proposed membranes  
714 showed a prolonged release resulting in marked antibacterial properties, mechanical properties suitable for  
715 wound dressing applications, and excellent cytocompatibility. Lately, Lv et al. (Y. Lv et al., 2021) prepared  
716  $\beta$ -cyclodextrin cellulose acetate nanofibers for the removal of bisphenol pollutants from water. The authors  
717 first modified native  $\beta$ CDs with tetrafluoroterephthalonitrile (TF) by a simple chemical treatment before  
718 grafting them onto the CA mats to enhance the pollutant adsorption efficiency. The obtained products  
719 showed a highly porous morphology, a stable crystal structure, and excellent thermal stability, as well as the  
720 abundance of surface functional groups. Noticeably, the authors demonstrated the capability of the proposed  
721 nanofibers to efficiently act as adsorbent materials in a broad range of conditions for several cycles  
722 indicating their suitability for practical applications.

723 *Hydroxypropyl cellulose* (HPC) is another cellulose derivative showing good solubility in both water and  
724 organic solvents and mainly used as an excipient, lubricant and ophthalmic protectant owing to its thermo-  
725 and pH-responsive properties (Qiu & Hu, 2013; Yang & Li, 2018). In this regard, Aytac et al. (Aytac et al.,  
726 2015) presented the preparation of HPC nanofibers functionalized with the inclusion complex between  
727 hydroxypropyl- $\beta$ -cyclodextrin and sulfisoxazole (SFS) for drug delivery applications by developing  
728 sandwich-like multilayer materials. Compared to nanofibers containing the free drug, HPC/HP $\beta$ CD-ICs-SFS

729 mats showed a considerably higher release most likely owing to the enhanced incorporation of SFS through  
730 inclusion complexation.

731 *Almond gum* (ALG) is a natural gum copiously exuded from the trunk, branches, and fruits of *Prunus*  
732 *amygdalus* trees after mechanical injury and/or infection by microorganisms. Almond gum represents an  
733 important waste product in several developing countries and, owing to its antibacterial and antioxidant  
734 activities, could be successfully employed as a green alternative to several synthetic materials (Bouaziz et al.,  
735 2017). The release mechanism of curcumin from almond gum/PVA/ $\beta$ CD-ICs-curcumin electrospun  
736 membranes in simulated saliva and gastrointestinal conditions was investigated by Rezaei et al. (Rezaei &  
737 Nasirpour, 2019). Compared to the nanofibers loaded with free curcumin, the presence of  $\beta$ CD-curcumin ICs  
738 allowed to reach a much higher compound encapsulation efficiency (i.e., > 90%) and enriched the  
739 membranes with a greater and faster release, thus proving the possibility to use almond gum-based  
740 composite nanofibers as efficient drug delivery systems.

741 *Hyaluronic acid* (HA) is an anionic polysaccharide present in several human tissues with unique physical-  
742 chemical properties and a wide range of important biological functions, including cell signalling, wound  
743 reparation, tissue regeneration, morphogenesis, matrix organization and pathobiology (Dodero, Williams, et  
744 al., 2019; Fallacara et al., 2018). Séon-Lutz et al. (Séon-Lutz et al., 2019) reported on the preparation of HA-  
745 PVA membranes functionalized with HP $\beta$ CDs for wound dressing applications using only water as solvent.  
746 The membranes were thereafter crosslinked with a carbodiimide and N-hydroxysuccinimide ensuring thus a  
747 completely green process of fabrication. The authors proved that the use of HP $\beta$ CDs stabilized the  
748 electrospinning process owing to their capability to establish intermolecular interactions with HA and PVA,  
749 thus allowing to noticeably reduce the minimum concentration of co-spinning agent (i.e., PVA). More  
750 importantly, naproxen (NAP) drug was a posteriori encapsulated within the prepared nanofibers and  
751 presented a sustained release over several days.

752 *Dandelion* (DP) is an  $\alpha$ -type polysaccharide extracted from the roots of a perennial herbaceous plant and  
753 currently employed in several food products owing to its antitumor, antioxidant, and anti-complement  
754 properties (Guo et al., 2019). Cui et al. (Cui et al., 2019) reported on the preparation of nanofibrous  
755 dandelion-based membranes embedding  $\beta$ CD-ICs-Litsea cubeba essential oil (LCEO) as efficient  
756 antibacterial agents. The structure of the mats was improved thanks to the addition of the  $\beta$ CD complexes in



757 the spinning solutions owing to the interactions between the components. Interestingly, a sustained release of  
758 the encapsulated LCEO was observed over several days resulting in marked antibacterial properties,  
759 therefore making the prepared nanofibers suitable to be used for both biomedical and food packaging  
760 purposes.

761

## 762 **6.2 Electrospun Protein – Cyclodextrin Based Membranes**

763 Proteins are biomacromolecules composed of long amino acid chains with an important role in several body  
764 functions such as DNA replication, metabolic reactions, stimuli responses, and moieties transportation, as  
765 well as in cell viability. Proteins are biocompatible, biodegradable, easily accustomed in the human body,  
766 and with interesting isoelectric properties that allow them to interact with a wide variety of molecules  
767 (Muiznieks & Keeley, 2017; Sheng Wang et al., 2016; Weisel & Litvinov, 2017). Owing to such properties,  
768 it is not surprising that protein-based electrospun membranes are gaining increasing interest for several  
769 applications, especially in the food packaging and biomedical industries. However, proteins are known to be  
770 infamously difficult to be electrospun because of their complex secondary and ternary structures, with  
771 globular properties having too few interactions to form a sufficient number of entanglements (Babitha et al.,  
772 2017; DeFrates et al., 2018; Ding et al., 2019; Kakoria & Sinha-Ray, 2018; Zhong et al., 2018).

773 Protein-based nanofibrous membranes functionalized with cyclodextrins represent an emerging and  
774 interesting class of novel materials with the possibility to couple the outstanding properties of both  
775 components. However, their investigation remains to an initial stage with only a small number of  
776 publications reported in the literature as summarized in Table 3.

**Table 3.** Comprehensive summary of protein-based electrospun membranes functionalized with CDs or CD-ICs and their main applications.

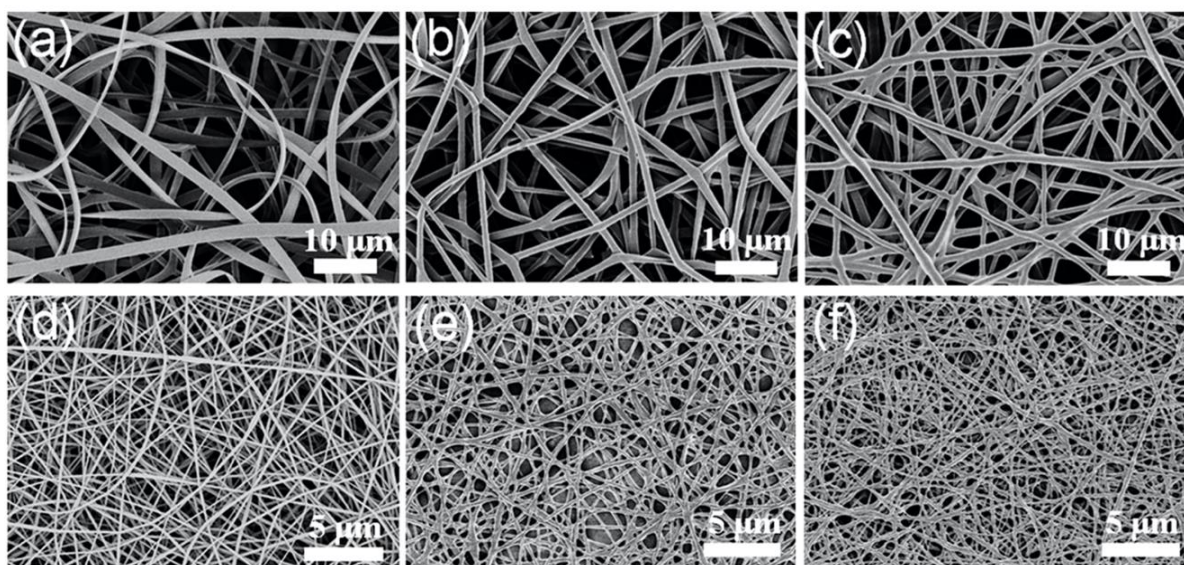
Protein	Cyclodextrins	Encapsulated bioactive molecules	Applications	Ref.
Soy protein isolate	$\beta$ CDs	Allyl isothiocyanate	Food packaging materials with enhanced encapsulation efficiency and humidity triggered release kinetic	(Vega-Lugo & Lim, 2009)
	$\alpha$ CDs	---	Fundamental study of the effect of CDs on zein solution spinnability	(Kayaci & Uyar, 2012a)
Zein	$\beta$ CDs	---	Fundamental study of the effect of CDs on zein solution spinnability	(Kayaci & Uyar, 2012a)
		Eucalyptus essential oil	Antibacterial food packaging products with enhanced thermal stability	(Dias Antunes et al., 2017)
	$\gamma$ CDs	Quercetin	Antibacterial food packaging products	(Z. Wang et al., 2021)
		---	Fundamental study of the effect of CDs on zein solution spinnability	(Kayaci & Uyar, 2012a)
		Thymol	Antibacterial food packaging products with enhanced release properties	(Aytac, Ipek, et al., 2017)
		Quercetin	Water-insoluble food packaging materials with fast antioxidant action	(Aytac, Ipek, et al., 2018)
Silk fibroin	HP $\beta$ CDs	Tamoxifen	Transdermal drug delivery systems with prolonged-release kinetic for the treatment of breast cancer	(W. Liu et al., 2016)
Gelatin	$\beta$ CDs	---	Water-insoluble crosslinked nanofibers as cost-effective water pollutant removal	(Yu Chen et al., 2018)
		---	Respiratory filter media for filtration of aerosols and volatile organic compounds	(Kadam et al., 2021)
		Galangal root oil	Active food packaging products with antibacterial properties	(Zhou et al., 2020)
	HP $\beta$ CDs	Ciprofloxacin	Fast-dissolving drug delivery systems for oral formulation dosages	(Aytac et al., 2019)
Gliadin	HP $\beta$ CDs	Ferulic acid	Biomedical and food products with enhanced thermal stability and fast release properties	(Sharif et al., 2018)
Hordein	$\beta$ CDs	N,N'-methylene bisacrylamide	Recyclable filter materials for the efficient removal of heavy metals from wastewater	(Guan et al., 2019)

778 *Soy protein isolate* (SPI) is the most refined protein obtained from soybean with several applications in  
779 food-related products due to its great abundance and high availability as by-products from industries (Rani &  
780 Kumar, 2019; Tian et al., 2018). SPI was the first protein employed to prepare protein-based electrospun  
781 nanofibers functionalized with cyclodextrins by Vega-Lugo et al. (Vega-Lugo & Lim, 2009), who reported  
782 on SPI nanofibers encapsulating allyl isothiocyanate compound (AITC) by using  $\beta$ CDs as complexation  
783 agents and PEO as a co-spinning agent. Beyond the possibility to tune the nanofiber structure by simple  
784 changing the mixture composition, AITC release kinetics from the composite nanofibers strongly depended  
785 on the environment relative humidity. Specifically, no compound loss was observed at 0% RH, whereas a  
786 sustained release for 20h was detected at 75% RH comparably to the results showed by Aytac et al.  
787 concerning PVA/ $\beta$ CD-ICs-AITC membranes (Aytac et al., 2014).

788 *Zein* (ZN) is a clear, odourless, tasteless, water-insoluble and edible prolamin protein derived from corn and  
789 broadly employed in several commercial products ranging from the textile fiber market to the food industry  
790 (Kasaai, 2017; Turasan & Kokini, 2017; Yong Zhang et al., 2016). Kayaci et al. (Kayaci & Uyar, 2012a) first  
791 reported on a fundamental study regarding the preparation of zein nanofibers encapsulating different amount  
792 of  $\alpha$ CDs,  $\beta$ CDs, or  $\gamma$ CDs. Comparably to what was reported by other research groups for polysaccharides,  
793 the addition of CDs noticeably improved the spinnability of pristine zein solutions leading to bead-free  
794 nanofibers, with only a slight morphological dependence on the cyclodextrin type, and enhanced thermal  
795 stability. Owing to the abovementioned finding and keeping in mind cyclodextrin complexation capability,  
796 the authors indicated that these nanofibrous mats are promising products for biomedical and food packaging  
797 applications. Subsequently, Aytac et al. (Aytac, Ipek, et al., 2017) prepared zein nanofibers functionalized  
798 with the inclusion complexes between  $\gamma$ -cyclodextrins and thymol, which were able to provide a high  
799 encapsulation capability leading to enhanced stability and release kinetic. Moreover, by testing the  
800 antibacterial properties toward *E. Coli* and *S. Aureus* bacteria in meat simulated storage conditions at  $T =$   
801  $4\text{ }^{\circ}\text{C}$ , the prepared mats were suggested as promising antibacterial food packaging materials. Similar work  
802 was reported by Antunes et al. (Dias Antunes et al., 2017), who proposed the encapsulation of  $\beta$ -  
803 cyclodextrin-eucalyptus essential oil complexes in zein electrospun nanofibers by using aqueous ethanol  
804 (EtOH) eco-friendly mixture as solvent. SEM images proved the good homogeneity of the obtained  
805 nanofibers, which contained around 24% of the formed inclusion complexes. Moreover, the antibacterial

properties were tested against *S. aureus* and *Listeria monocytogenes* (*L. monocytogenes*) bacteria showing a strong growth reduction and the possibility to use the obtained mats for applications in the food packaging. More recently, Aytac et al. (Aytac, Ipek, et al., 2018) reported on electrospun zein/ $\gamma$ CD-ICs-quercetin nanofibers as quick and efficient antioxidant materials, with the encapsulated quercetin showing enhanced thermal stability and water solubility compared to its free form. Similarly, Wang et al. (Z. Wang et al., 2021) prepared homogenous and free-standing zein nanofibers embedding  $\beta$ CD-ICs-quercetin. The encapsulation of the bioactive compound was proved to improve its availability, release time, and thermal stability. Consequently, the obtained mats showed strong antibacterial properties against both *E. Coli* and *S. Aureus* bacteria, thus resulting in promising materials for future active food packaging products.

*Silk fibroin* (SF) is an insoluble protein largely produced by the larvae of *Bombyx mori* and numerous other insects. SF has assumed an increasing interest in biomedical applications owing to its biocompatibility, low immunogenicity, mechanical properties, and ability to remodel in response to the biological environment (Koh et al., 2018; Qi et al., 2017). With this premises, Liu et al. (W. Liu et al., 2016) demonstrated the possibility to prepare regenerated silk fibroin (RSF) nanofibers embedding HP $\beta$ CD-ICs-tamoxifen (TAM) as potential drug delivery systems by using a simple aqueous mixture. The complex addition strongly increased the spinnability of RSF solutions leading to thinner and more homogenous nanofibers as shown in Figure 8, whereas the encapsulated drug was slowly released over 3 weeks making RSF cyclodextrin-functionalized nanofibers promising products as transdermal drug delivery systems.



**Figure 8.** SEM micrographs of (a) as-spun RSF nanofibers, (b) RSF nanofibers after ethanol spraying treatment, (c) RSF nanofibers after acetone immersion treatment, (d) as-spun RSF/HP $\beta$ CD-ICs-TAM nanofibers, (e) RSF/HP $\beta$ CD-ICs-TAM nanofibers after ethanol spraying treatment, (f) RSF/HP $\beta$ CD-ICs-TAM nanofibers after acetone immersion treatment. Reproduced with permission from W. Liu et al., 2016. © 2016 Elsevier B.V.

*Gelatin* (GL) is a largely available protein obtained from animal products and broadly employed in manufacturing to prepare foods, cosmetics and medicines owing to its gelling properties and ability to improve product elasticity, consistency and stability (Hosseini & Gómez-Guillén, 2018; Karayannakidis & Zotos, 2016). The use of gelatin/ $\beta$ -cyclodextrins nanofibers for the removal of dyes from wastewater was proposed by Chen et al. (Yu Chen et al., 2018). The authors developed a crosslinking approach with glutaraldehyde vapour both to stabilize the nanofibers and permanently grafting the cyclodextrins to the polymer chains avoiding leaking issues. Remarkably, the prepared mats showed promising adsorption capability towards methylene blue in different experimental conditions and several other common dyes, being above all characterized by good recyclability and reusability, therefore representing cost-effective and promising products for the efficient purification of wastewater. Yet, Aytac et al. (Aytac et al., 2019) investigated the use of gelatin nanofibers loaded with HP $\beta$ CD and ciprofloxacin (CIP) complexes as fast-dissolving drug delivery systems. The authors were able to prove that the bead-free nanofibers encapsulating HP $\beta$ CD-ICs-CIP showed to be more rapidly dissolved compared to gelatin/CIP nanofibers, thus pointing out the capability of HP $\beta$ CDs in increasing the sample wettability and opening the way to the preparation of a broad variety of drug delivery systems able to quickly release high drug dosages. Additionally, Zhou et al.

(Zhou et al., 2020) investigated the preparation of gelatin-based nanofibers containing the inclusion complex between  $\beta$ CDs and galangal root oil (GRO). By using different gelatin sources, the authors evaluated how the composition of the protein amino acids affected the electrospinning process. Remarkably, gelatin/ $\beta$ CD-ICs-GRO showed marked antibacterial properties against E Coli, as well as excellent mechanical and thermal properties, thus being suitable as food packaging materials. Lately, Kadam et al. (Kadam et al., 2021) reported on the preparation of gelatin/ $\beta$ CDs nanofibers to be used as filter materials. In particular, the possibility to easily control the fiber dimension and the mat porosity, coupled with the cyclodextrin inclusion complex capabilities, allowed the prepared materials to show filtration efficiency towards both solid/liquid particles and VOCs.

*Gliadin* (GD) is a prolamin protein largely present in wheat, as well as in other cereals, with a wide range of interesting applications (Jia et al., 2020; Urade et al., 2018). Sharif et al. (Sharif et al., 2018) reported on the encapsulation of HP $\beta$ CD-ICs-ferulic acid within gliadin electrospun nanofibers. The complexation phenomenon allowed to increase both the thermal and photostability of FA thus preserving its antioxidant properties. Noticeably, compared to the GL nanofibers containing free FA, gliadin/HP $\beta$ CD-ICs-FA mats showed a superior and faster release of the bioactive compound in artificial media simulating different food or biological conditions.

*Hordein* (HD), likewise gliadin, is a prolamin protein present in barley and other cereals and mainly used for food applications (X. Huang et al., 2017). Guan et al. (Guan et al., 2019) proposed hordein nanofibrous membranes embedding N,N'-methylene bisacrylamide (MBA) molecules and grafted with  $\beta$ CDs for the adsorption of copper ions. The uptake properties of the prepared mats were evaluated at different pH and temperature conditions with the hordein/ $\beta$ CD-ICs-MBA nanofibers showing higher adsorption capability both compared to hordein/MBA and hordein electrospun mats. Additionally, the authors were able to prove the recyclability of the obtained mats via a humble and cost-effective washing procedure hence demonstrating their efficient use for the treatment of wastewater.

## 872    **7    Conclusions and Future Perspectives**

873    Nowadays, electrospinning is worldwide recognized as a simple, flexible, and cost-effective technique for  
874    the preparation of nano- and microfibers with applicability in almost any research field and it has become, in  
875    the last decade, one of the most promising approaches to improve human quality of life via the production of  
876    tailored-made products for biomedical, food, energy harvesting, textile and environmental purposes. In this  
877    sense, cyclodextrins may play a very important role and their use in combination with electrospinning has  
878    aroused growing interest. Specifically, in most cases, the objective is to prepare polymer-free cyclodextrin  
879    nanofibers able to efficiently encapsulate bioactive compounds and accurately control their release. Indeed,  
880    the outstanding capability of cyclodextrins to form non-covalent stable complexes with small molecules (e.g.,  
881    hydrophobic and/or volatile compounds) allows to considerably increase their solubility, stability, and  
882    availability, hence leading to a superior encapsulation efficiency that was previously unreachable. However,  
883    a variety of innovative applications are recently being evaluated for electrospun nanofibers made of (or  
884    containing) cyclodextrins and their derivatives, also creditable to the fact that their preparation allows  
885    avoiding the intensive use of toxic solvents and/or hazardous chemicals. For instance, cyclodextrin-based  
886    nanofibers can be employed as reducing agents for the in-situ synthesis of metal nanoparticles, as sacrificial  
887    templates for the development of conductive hollow structures, as implantable scaffolds for tissue  
888    regeneration purposes, as well as to develop high performing filtering materials and food packaging products  
889    with antibacterial and antioxidant properties.

890    Additionally, combining the complexation capability of cyclodextrins with naturally occurring biopolymers  
891    appears to be the optimal format for the development of mats with unique and tuneable features. For instance,  
892    besides biocompatibility and greater biological response, biodegradability and digestibility, the greatest  
893    advantage of natural biopolymers is that they can be processed by using water or poorly toxic organic  
894    solvents making them extremely interesting from an industrial point of view. Moreover, the continuous  
895    advances in the extraction of materials from natural waste sources may lead in the future to the development  
896    of environmentally friendly electrospun products in view of a green circular economy. However, the  
897    development of these strategies remains at an initial stage and further studies are required since, at present,  
898    the electrospinning of natural biopolymers requires appropriate additives to facilitate the processing, as well  
899    as post-processing treatments to increase the mat stability and mechanical performances without affecting the

900 intrinsic biocompatibility. Noticeably, it is noteworthy that cyclodextrins have been demonstrated able to  
901 enhance the spinnability of biopolymer-based formulations due to the tendency to create supramolecular  
902 structures with the biopolymers, thus reducing, or even eliminating, the amount of required synthetic co-  
903 spinning agents. Nevertheless, despite the considerable advances recently made at the laboratory scale, the  
904 industrial implementation of natural polymer electrospinning has been scarcely explored and remains a great  
905 challenge especially in terms of production rate.

906 In conclusion, in order to ensure the efficient translation between laboratory prototypes and commercial  
907 products, workability studies are mandatory to verify the effective applicability of cyclodextrin-based  
908 electrospun membranes for the proposed applications and more research-industry collaborations are  
909 indispensable to lower the cost and improve the industrialization of such materials.

910

#### 911 **Conflict of Competing Interest**

912 None.

913

#### 914 **Funding**

915 This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-  
916 profit sectors.



917	<b>Abbreviations</b>	
918	AA	Acetic acid
919	AAB	Azobenzene
920	AFM	Atomic force microscopy
921	Ag	Silver
922	Ag-NPs	Silver nanoparticles
923	AITC	Allyl isothiocyanate compound
924	Al	Aluminium
925	Al <sub>2</sub> O <sub>3</sub>	Aluminium oxide
926	ALD	Atomic layer deposition
927	ALG	Almond gum
928	Au	Gold
929	Au-NPs	Gold nanoparticles
930	a <sub>w</sub>	Water activity
931	BA	Benzoxazine
932	BET	Brunauer – Emmett – Teller
933	Botrytis sp.	Botrytis species
934	BTCA	Butanetetracarboxylic acid
935	CA	Cellulose acetate
936	CTR	Citric acid
937	CD-ICs	Cyclodextrin inclusion complexes
938	CDs	Cyclodextrins
939	c <sub>e</sub>	Entanglement concentration
940	CH	Chitosan
941	CIP	Ciprofloxacin
942	CMβCDs	Carboxymethyl-β-cyclodextrins
943	COL	Collagen
944	Cr	Chromium

945	Cu	Copper
946	DCF	Diclofenac sodium
947	DDSs	Drug delivery systems
948	DLS	Dynamic light scattering
949	DMA	Dynamic-mechanical analysis
950	DMAc	Dimethylacetamide
951	DMF	Dimethylformamide
952	DMSO	Dimethyl sulfoxide
953	DNA	Deoxyribonucleic acid
954	DOX	Doxycycline
955	DP	Dandelion
956	DSC	Differential scanning calorimetry
957	E. Coli	Escherichia Coli
958	ECH	Epichlorohydrin
959	ECM	Extra-cellular matrix
960	EDS	Energy-dispersive X-ray spectroscopy
961	ES	Electrospinning
962	EtOH	Ethanol
963	FA	Ferulic acid
964	Fe	Iron
965	Fe-NPs	Iron nanoparticles
966	FTIR	Fourier-transform infrared spectroscopy
967	GD	Gliadin
968	GL	Gelatin
969	GRO	Galangal root oil
970	HA	Hyaluronic acid
971	HD	Hordein
972	HPC	Hydroxypropyl cellulose

973	HP $\alpha$ CDs	2-hydroxypropyl- $\alpha$ CDs
974	HP $\beta$ CDs	2-hydroxypropyl- $\beta$ CDs
975	HP $\gamma$ CDs	2-hydroxypropyl- $\gamma$ CDs
976	HSES	High speed electrospinning
977	IKAV	Adamantane-6-aminohexanoic acid-GGKIKVAV-Am
978	KK	Adamantane-6-aminohexanoic acid-GGKK-Am
979	<i>L. monocytogenes</i>	<i>Listeria monocytogenes</i>
980	LCEO	Litsea cubeba essential oil
981	MB	Methylene blue
982	MBA	N,N'-methylene bisacrylamide
983	MO	Methyl orange
984	M $\beta$ CDs	Randomly methylated- $\beta$ CDs
985	NaOH	Sodium hydroxide
986	NAP	Naproxen
987	Ni	Nickel
988	NMR	Nuclear magnetic resonance spectroscopy
989	NPs	Nanoparticles
990	PAA	Poly(acrylic acid)
991	PAN	Polyacrylonitrile
992	PAP	p-aminophenol
993	PCL	Polycaprolactone
994	Pd	Palladium
995	Pd-NPs	Palladium nanoparticles
996	PEO	Poly(ethylene oxide)
997	PET	Polyethylene terephthalate
998	PHAs	Polycyclic aromatic hydrocarbons
999	PLA	Polylactic acid
1000	PMMA	Polymethylmethacrylate

1001	PNP	p-nitrophenol
1002	PolyBA-a	Poly benzoxazine
1003	PolyCDs	Cyclodextrin-based polymers
1004	PolyHP $\beta$ CDs	Poly-2-hydroxypropyl- $\beta$ CDs
1005	PS	Polystyrene
1006	PUL	Pullulan
1007	PVA	Polyvinyl alcohol
1008	PVP	Polyvinylpyrrolidone
1009	RC	Regenerated cellulose
1010	RH	Relative humidity
1011	RSF	Regenerated silk fibroin
1012	S. Aureus	Staphylococcus Aureus
1013	SA	Sodium alginate
1014	SEB $\beta$ CDs	Sulfobutylether- $\beta$ -cyclodextrins
1015	SEM	Scanning electron microscopy
1016	SF	Silk fibroin
1017	SFS	Sulfisoxazole
1018	SHP	Sodium hypophosphite
1019	SPI	Soy protein isolate
1020	SV	Simvastatin
1021	SBG	Swim bladder gelatin
1022	TAM	Tamoxifen
1023	TBZ	Thiabendazole
1024	TCL	Triclosan
1025	TEM	Transmission electron microscopy
1026	TF	Tetrafluoroterephthalonitrile
1027	TFA	Trifluoroacetic acid
1028	TGA	Thermogravimetric analysis

1029	THY	Thymol
1030	UV	Ultraviolet
1031	UV-vis	Ultraviolet-visible
1032	VB <sub>2</sub>	Vitamin B <sub>2</sub>
1033	VOCs	Volatile organic compounds
1034	VOR	Voriconazole
1035	WAXS	Wide-angle X-ray scattering
1036	XPS	X-ray photoelectron spectroscopy
1037	XRD	X-ray diffraction
1038	ZN	Zein
1039	Zn	Zinc
1040	ZnO	Zinc oxide
1041	αCDs	α-cyclodextrins
1042	α-LA	alpha-lipoic acid
1043	βCDs	β-cyclodextrins
1044	γCDs	γ-cyclodextrin

## 1045     **References**

- 1046     Ahmed, F. E., Lalia, B. S., & Hashaikheh, R. (2015). A review on electrospinning for membrane fabrication:  
1047             Challenges and applications. *Desalination*, 356, 15–30. <https://doi.org/10.1016/j.desal.2014.09.033>
- 1048     Ahn, Y., Kang, Y., Ku, M., Yang, Y. H., Jung, S., & Kim, H. (2013). Preparation of  $\beta$ -cyclodextrin fiber  
1049             using electrospinning. *RSC Advances*, 3(35), 14983–14987. <https://doi.org/10.1039/c3ra42339e>
- 1050     Allais, M., Mailley, D., Hébraud, P., Ihiawakrim, D., Ball, V., Meyer, F., Hébraud, A., & Schlatter, G.  
1051             (2018). Polymer-free electrospinning of tannic acid and cross-linking in water for hybrid  
1052             supramolecular nanofibres. *Nanoscale*, 10(19), 9164–9173. <https://doi.org/10.1039/c8nr01067f>
- 1053     Alvarez-Lorenzo, C., García-González, C. A., & Concheiro, A. (2017). Cyclodextrins as versatile building  
1054             blocks for regenerative medicine. *Journal of Controlled Release*, 268(September), 269–281.  
1055             <https://doi.org/10.1016/j.jconrel.2017.10.038>
- 1056     Amiraliyan, N., Nouri, M., & Kish, M. H. (2009). Effects of some electrospinning parameters on  
1057             morphology of natural silk-based nanofibers. *Journal of Applied Polymer Science*, 113(1), 226–234.  
1058             <https://doi.org/10.1002/app.29808>
- 1059     Amiri, S., & Rahimi, A. (2019). Poly( $\epsilon$ -caprolactone) electrospun nanofibers containing cinnamon essential  
1060             oil nanocapsules: A promising technique for controlled release and high solubility. *Journal of*  
1061             *Industrial Textiles*, 48(10), 1527–1544. <https://doi.org/10.1177/1528083718764911>
- 1062     Anton, F. (1934). *Process and apparatus for preparing artificial threads*.
- 1063     Aytac, Z., Celebioglu, A., Yildiz, Z. I., & Uyar, T. (2018). Efficient encapsulation of citral in fast-dissolving  
1064             polymer-free electrospun nanofibers of cyclodextrin inclusion complexes: High thermal stability,  
1065             longer shelf-life, and enhanced water solubility of citral. *Nanomaterials*, 8(10), 1–15.  
1066             <https://doi.org/10.3390/nano8100793>
- 1067     Aytac, Z., Dogan, S. Y., Tekinay, T., & Uyar, T. (2014). Release and antibacterial activity of allyl  
1068             isothiocyanate/ $\beta$ -cyclodextrin complex encapsulated in electrospun nanofibers. *Colloids and Surfaces*  
1069             *B: Biointerfaces*, 120, 125–131. <https://doi.org/10.1016/j.colsurfb.2014.04.006>
- 1070     Aytac, Z., Ipek, S., Durgun, E., Tekinay, T., & Uyar, T. (2017). Antibacterial electrospun zein nanofibrous  
1071             web encapsulating thymol/cyclodextrin-inclusion complex for food packaging. *Food Chemistry*, 233,  
1072             117–124. <https://doi.org/10.1016/j.foodchem.2017.04.095>

1073 Aytac, Z., Ipek, S., Durgun, E., & Uyar, T. (2018). Antioxidant electrospun zein nanofibrous web  
 1074 encapsulating quercetin/cyclodextrin inclusion complex. *Journal of Materials Science*, 53(2), 1527–  
 1075 1539. <https://doi.org/10.1007/s10853-017-1580-x>

1076 Aytac, Z., Ipek, S., Erol, I., Durgun, E., & Uyar, T. (2019). Fast-dissolving electrospun gelatin nanofibers  
 1077 encapsulating ciprofloxacin/cyclodextrin inclusion complex. *Colloids and Surfaces B: Biointerfaces*,  
 1078 178(February), 129–136. <https://doi.org/10.1016/j.colsurfb.2019.02.059>

1079 Aytac, Z., Sen, H. S., Durgun, E., & Uyar, T. (2015). Sulfisoxazole/cyclodextrin inclusion complex  
 1080 incorporated in electrospun hydroxypropyl cellulose nanofibers as drug delivery system. *Colloids and*  
 1081 *Surfaces B: Biointerfaces*, 128, 331–338. <https://doi.org/10.1016/j.colsurfb.2015.02.019>

1082 Aytac, Z., & Uyar, T. (2017). Core-shell nanofibers of curcumin/cyclodextrin inclusion complex and  
 1083 polylactic acid: Enhanced water solubility and slow release of curcumin. *International Journal of*  
 1084 *Pharmaceutics*, 518(1–2), 177–184. <https://doi.org/10.1016/j.ijpharm.2016.12.061>

1085 Aytac, Z., Yildiz, Z. I., Kayaci-Senirmak, F., San Keskin, N. O., Kusu, S. I., Durgun, E., Tekinay, T., &  
 1086 Uyar, T. (2016). Fast-Dissolving, Prolonged Release, and Antibacterial Cyclodextrin/Limonene-  
 1087 Inclusion Complex Nanofibrous Webs via Polymer-Free Electrospinning. *Journal of Agricultural and*  
 1088 *Food Chemistry*, 64(39), 7325–7334. <https://doi.org/10.1021/acs.jafc.6b02632>

1089 Aytac, Z., Yildiz, Z. I., Kayaci-Senirmak, F., San Keskin, N. O., Tekinay, T., & Uyar, T. (2016).  
 1090 Electrospinning of polymer-free cyclodextrin/geraniol-inclusion complex nanofibers: Enhanced shelf-  
 1091 life of geraniol with antibacterial and antioxidant properties. *RSC Advances*, 6(52), 46089–46099.  
 1092 <https://doi.org/10.1039/c6ra07088d>

1093 Aytac, Z., Yildiz, Z. I., Kayaci-Senirmak, F., Tekinay, T., & Uyar, T. (2017). Electrospinning of  
 1094 cyclodextrin/linalool-inclusion complex nanofibers: Fast-dissolving nanofibrous web with prolonged  
 1095 release and antibacterial activity. *Food Chemistry*, 231, 192–201.  
 1096 <https://doi.org/10.1016/j.foodchem.2017.03.113>

1097 Babitha, S., Rachita, L., Karthikeyan, K., Shoba, E., Janani, I., Poornima, B., & Purna Sai, K. (2017).  
 1098 Electrospun protein nanofibers in healthcare: A review. In *International Journal of Pharmaceutics* (Vol.  
 1099 523, Issue 1, pp. 52–90). Elsevier B.V. <https://doi.org/10.1016/j.ijpharm.2017.03.013>

1100 Balogh, A., Horváthová, T., Fülöp, Z., Loftsson, T., Harasztos, A. H., Marosi, G., & Nagy, Z. K. (2015).

Electroblowing and electrospinning of fibrous diclofenac sodium-cyclodextrin complex-based reconstitution injection. *Journal of Drug Delivery Science and Technology*, 26, 28–34. <https://doi.org/10.1016/j.jddst.2015.02.003>

Balusamy, B., Celebioglu, A., Senthamizhan, A., & Uyar, T. (2020). Progress in the design and development of “fast-dissolving” electrospun nanofibers based drug delivery systems - A systematic review. In *Journal of Controlled Release* (Vol. 326, pp. 482–509). Elsevier B.V. <https://doi.org/10.1016/j.jconrel.2020.07.038>

Bazhban, M., Nouri, M., & Mokhtari, J. (2013). Electrospinning of cyclodextrin functionalized chitosan/PVA nanofibers as a drug delivery system. *Chinese Journal of Polymer Science (English Edition)*, 31(10), 1343–1351. <https://doi.org/10.1007/s10118-013-1309-5>

Beachley, V., & Wen, X. (2010). Polymer nanofibrous structures: Fabrication, biofunctionalization, and cell interactions. In *Progress in Polymer Science (Oxford)* (Vol. 35, Issue 7, pp. 868–892). Pergamon. <https://doi.org/10.1016/j.progpolymsci.2010.03.003>

Becerril, R., Nerín, C., & Silva, F. (2020). Encapsulation Systems for Antimicrobial Food Packaging Components: An Update. *Molecules*, 25(5), 1134. <https://doi.org/10.3390/molecules25051134>

Bertasa, M., Doderio, A., Alloisio, M., Vicini, S., Riedo, C., Sansonetti, A., Scalarone, D., & Castellano, M. (2020). Agar gel strength: A correlation study between chemical composition and rheological properties. *European Polymer Journal*, 123, 109442. <https://doi.org/10.1016/j.eurpolymj.2019.109442>

Bethanis, K., Tzamalís, P., Tsorteki, F., Kokkinou, A., Christoforides, E., & Mentzafos, D. (2013). Structural study of the inclusion compounds of thymol, carvacrol and eugenol in  $\beta$ -cyclodextrin by X-ray crystallography. *Journal of Inclusion Phenomena and Macrocyclic Chemistry*, 77(1–4), 163–173. <https://doi.org/10.1007/s10847-012-0230-9>

Blanchemain, N., Laurent, T., Chai, F., Neut, C., Haulon, S., Krump-konvalinkova, V., Morcellet, M., Martel, B., Kirkpatrick, C. J., & Hildebrand, H. F. (2008). Polyester vascular prostheses coated with a cyclodextrin polymer and activated with antibiotics: Cytotoxicity and microbiological evaluation. *Acta Biomaterialia*, 4(6), 1725–1733. <https://doi.org/10.1016/j.actbio.2008.07.001>

Boas, M., Gradys, A., Vasilyev, G., Burman, M., & Zussman, E. (2015). Electrospinning polyelectrolyte complexes: PH-responsive fibers. *Soft Matter*, 11(9), 1739–1747. <https://doi.org/10.1039/c4sm02618g>



1129 Bouaziz, F., Koubaa, M., Ellouz Ghorbel, R., & Ellouz Chaabouni, S. (2017). Biological properties of water-  
 1130 soluble polysaccharides and hemicelluloses from almond gum. *International Journal of Biological*  
 1131 *Macromolecules*, 95, 667–674. <https://doi.org/10.1016/j.ijbiomac.2016.11.104>

1132 Burns, N. A., Burroughs, M. C., Gracz, H., Pritchard, C. Q., Brozena, A. H., Willoughby, J., & Khan, S. A.  
 1133 (2015). Cyclodextrin facilitated electrospun chitosan nanofibers. *RSC Advances*, 5(10), 7131–7137.  
 1134 <https://doi.org/10.1039/c4ra09662b>

1135 Candido, R. G., & Gonçalves, A. R. (2016). Synthesis of cellulose acetate and carboxymethylcellulose from  
 1136 sugarcane straw. *Carbohydrate Polymers*, 152, 679–686. <https://doi.org/10.1016/j.carbpol.2016.07.071>

1137 Cashion, M. P., Li, X., Geng, Y., Hunley, M. T., & Long, T. E. (2010). Gemini surfactant electrospun  
 1138 membranes. *Langmuir*, 26(2), 678–683. <https://doi.org/10.1021/la902287b>

1139 Castellano, M., Alloisio, M., Darawish, R., Doderio, A., & Vicini, S. (2019). Electrospun composite mats of  
 1140 alginate with embedded silver nanoparticles. *Journal of Thermal Analysis and Calorimetry*, 137(3),  
 1141 767–778. <https://doi.org/10.1007/s10973-018-7979-z>

1142 Cazón, P., Velazquez, G., Ramírez, J. A., & Vázquez, M. (2017). Polysaccharide-based films and coatings  
 1143 for food packaging: A review. *Food Hydrocolloids*, 68, 136–148.  
 1144 <https://doi.org/10.1016/j.foodhyd.2016.09.009>

1145 Ceborska, M. (2016). Structural investigation of the  $\beta$ -cyclodextrin complexes with linalool and  
 1146 isopinocampheol - Influence of monoterpenes cyclicality on the host-guest stoichiometry. *Chemical*  
 1147 *Physics Letters*, 651, 192–197. <https://doi.org/10.1016/j.cplett.2016.03.051>

1148 Celebioglu, A., Aytac, Z., Kilic, M. E., Durgun, E., & Uyar, T. (2018). Encapsulation of camphor in  
 1149 cyclodextrin inclusion complex nanofibers via polymer-free electrospinning: enhanced water solubility,  
 1150 high temperature stability, and slow release of camphor. *Journal of Materials Science*, 53(7), 5436–  
 1151 5449. <https://doi.org/10.1007/s10853-017-1918-4>

1152 Celebioglu, A., Aytac, Z., Umu, O. C. O., Dana, A., Tekinay, T., & Uyar, T. (2014). One-step synthesis of  
 1153 size-tunable Ag nanoparticles incorporated in electrospun PVA/cyclodextrin nanofibers. *Carbohydrate*  
 1154 *Polymers*, 99, 808–816. <https://doi.org/10.1016/j.carbpol.2013.08.097>

1155 Celebioglu, A., Demirci, S., & Uyar, T. (2014). Cyclodextrin-grafted electrospun cellulose acetate nanofibers  
 1156 via “click” reaction for removal of phenanthrene. *Applied Surface Science*, 305, 581–588.

<https://doi.org/10.1016/j.apsusc.2014.03.138>

Celebioglu, A., Kayaci-Senirmak, F., Ipek, S., Durgun, E., & Uyar, T. (2016). Polymer-free nanofibers from vanillin/cyclodextrin inclusion complexes: High thermal stability, enhanced solubility and antioxidant property. *Food and Function*, 7(7), 3141–3153. <https://doi.org/10.1039/c6fo00569a>

Celebioglu, A., Sen, H. S., Durgun, E., & Uyar, T. (2016). Molecular entrapment of volatile organic compounds (VOCs) by electrospun cyclodextrin nanofibers. *Chemosphere*, 144, 736–744. <https://doi.org/10.1016/j.chemosphere.2015.09.029>

Celebioglu, A., Topuz, F., & Uyar, T. (2019a). Facile and green synthesis of palladium nanoparticles loaded into cyclodextrin nanofibers and their catalytic application in nitroarene hydrogenation. *New Journal of Chemistry*, 43(7), 3146–3152. <https://doi.org/10.1039/c8nj05133j>

Celebioglu, A., Topuz, F., & Uyar, T. (2019b). Water-Insoluble Hydrophilic Electrospun Fibrous Mat of Cyclodextrin–Epichlorohydrin Polymer as Highly Effective Sorbent. *ACS Applied Polymer Materials*, 1(1), 54–62. <https://doi.org/10.1021/acsapm.8b00034>

Celebioglu, A., Topuz, F., Yildiz, Z. I., & Uyar, T. (2019a). Efficient Removal of Polycyclic Aromatic Hydrocarbons and Heavy Metals from Water by Electrospun Nanofibrous Polycyclodextrin Membranes. *ACS Omega*, 4(4), 7850–7860. <https://doi.org/10.1021/acsomega.9b00279>

Celebioglu, A., Topuz, F., Yildiz, Z. I., & Uyar, T. (2019b). One-step green synthesis of antibacterial silver nanoparticles embedded in electrospun cyclodextrin nanofibers. *Carbohydrate Polymers*, 207(November 2018), 471–479. <https://doi.org/10.1016/j.carbpol.2018.12.008>

Celebioglu, A., Umu, O. C. O., Tekinay, T., & Uyar, T. (2014). Antibacterial electrospun nanofibers from triclosan/cyclodextrin inclusion complexes. *Colloids and Surfaces B: Biointerfaces*, 116, 612–619. <https://doi.org/10.1016/j.colsurfb.2013.10.029>

Celebioglu, A., & Uyar, T. (2010). Cyclodextrin nanofibers by electrospinning. *Chemical Communications*, 46(37), 6903–6905. <https://doi.org/10.1039/c0cc01484b>

Celebioglu, A., & Uyar, T. (2011). Electrospinning of polymer-free nanofibers from cyclodextrin inclusion complexes. *Langmuir*, 27(10), 6218–6226. <https://doi.org/10.1021/la1050223>

Celebioglu, A., & Uyar, T. (2012). Electrospinning of nanofibers from non-polymeric systems: Polymer-free nanofibers from cyclodextrin derivatives. *Nanoscale*, 4(2), 621–631.

1185 <https://doi.org/10.1039/c1nr11364j>

1186 Celebioglu, A., & Uyar, T. (2013a). Electrospinning of nanofibers from non-polymeric systems: Electrospun  
 1187 nanofibers from native cyclodextrins. *Journal of Colloid and Interface Science*, 404, 1–7.  
 1188 <https://doi.org/10.1016/j.jcis.2013.04.034>

1189 Celebioglu, A., & Uyar, T. (2013b). Electrospun gamma-cyclodextrin ( $\gamma$ -CD) nanofibers for the entrapment  
 1190 of volatile organic compounds. *RSC Advances*, 3(45), 22891–22895.  
 1191 <https://doi.org/10.1039/c3ra44870c>

1192 Celebioglu, A., & Uyar, T. (2013c). Green and one-step synthesis of gold nanoparticles incorporated into  
 1193 electrospun cyclodextrin nanofibers. *RSC Advances*, 3(26), 10197–10201.  
 1194 <https://doi.org/10.1039/c3ra41175c>

1195 Celebioglu, A., & Uyar, T. (2017). Antioxidant Vitamin E/Cyclodextrin Inclusion Complex Electrospun  
 1196 Nanofibers: Enhanced Water Solubility, Prolonged Shelf Life, and Photostability of Vitamin E. *Journal*  
 1197 *of Agricultural and Food Chemistry*, 65(26), 5404–5412. <https://doi.org/10.1021/acs.jafc.7b01562>

1198 Celebioglu, A., & Uyar, T. (2019a). Encapsulation and Stabilization of  $\alpha$ -Lipoic Acid in Cyclodextrin  
 1199 Inclusion Complex Electrospun Nanofibers: Antioxidant and Fast-Dissolving  $\alpha$ -Lipoic  
 1200 Acid/Cyclodextrin Nanofibrous Webs. *Journal of Agricultural and Food Chemistry*, 67(47), 13093–  
 1201 13107. <https://doi.org/10.1021/acs.jafc.9b05580>

1202 Celebioglu, A., & Uyar, T. (2019b). Fast Dissolving Oral Drug Delivery System Based on Electrospun  
 1203 Nanofibrous Webs of Cyclodextrin/Ibuprofen Inclusion Complex Nanofibers. *Molecular*  
 1204 *Pharmaceutics*, 16(10), 4387–4398. <https://doi.org/10.1021/acs.molpharmaceut.9b00798>

1205 Celebioglu, A., & Uyar, T. (2019c). Metronidazole/Hydroxypropyl- $\beta$ -Cyclodextrin inclusion complex  
 1206 nanofibrous webs as fast-dissolving oral drug delivery system. *International Journal of Pharmaceutics*,  
 1207 572(October), 118828. <https://doi.org/10.1016/j.ijpharm.2019.118828>

1208 Celebioglu, A., & Uyar, T. (2020a). Design of Polymer-free Vitamin-A acetate/Cyclodextrin Nanofibrous  
 1209 Webs: Antioxidant and Fast-dissolving Property. *Food & Function*. <https://doi.org/10.1039/d0fo01776k>

1210 Celebioglu, A., & Uyar, T. (2020b). Electrospinning of cyclodextrins: hydroxypropyl-alpha-cyclodextrin  
 1211 nanofibers. *Journal of Materials Science*, 55(1), 404–420. <https://doi.org/10.1007/s10853-019-03983-x>

1212 Celebioglu, A., & Uyar, T. (2020c). Fast-dissolving antioxidant curcumin/cyclodextrin inclusion complex

1213 electrospun nanofibrous webs. *Food Chemistry*, 317(January), 126397.  
 1214 <https://doi.org/10.1016/j.foodchem.2020.126397>  
 1215 Celebioglu, A., & Uyar, T. (2020d). Hydrocortisone/cyclodextrin complex electrospun nanofibers for a fast-  
 1216 dissolving oral drug delivery system. *RSC Medicinal Chemistry*, 11(2), 245–258.  
 1217 <https://doi.org/10.1039/c9md00390h>  
 1218 Celebioglu, A., & Uyar, T. (2020e). Development of ferulic acid/cyclodextrin inclusion complex nanofibers  
 1219 for fast-dissolving drug delivery system. *International Journal of Pharmaceutics*, 584, 119395.  
 1220 <https://doi.org/10.1016/j.ijpharm.2020.119395>  
 1221 Celebioglu, A., & Uyar, T. (2020f). Electrohydrodynamic encapsulation of eugenol-cyclodextrin complexes  
 1222 in pullulan nanofibers. *Food Hydrocolloids*, 111, 106264.  
 1223 <https://doi.org/10.1016/j.foodhyd.2020.106264>  
 1224 Celebioglu, A., & Uyar, T. (2021). Electrospun formulation of acyclovir/cyclodextrin nanofibers for fast-  
 1225 dissolving antiviral drug delivery. *Materials Science and Engineering C*, 118, 111514.  
 1226 <https://doi.org/10.1016/j.msec.2020.111514>  
 1227 Celebioglu, A., Vempati, S., Ozgit-Akgun, C., Biyikli, N., & Uyar, T. (2014). Water-soluble non-polymeric  
 1228 electrospun cyclodextrin nanofiber template for the synthesis of metal oxide tubes by atomic layer  
 1229 deposition. *RSC Advances*, 4(106), 61698–61705. <https://doi.org/10.1039/c4ra12073f>  
 1230 Celebioglu, A., Yildiz, Z. I., & Uyar, T. (2017). Electrospun crosslinked poly-cyclodextrin nanofibers:  
 1231 Highly efficient molecular filtration thru host-guest inclusion complexation. *Scientific Reports*, 7(1), 1–  
 1232 11. <https://doi.org/10.1038/s41598-017-07547-4>  
 1233 Celebioglu, A., Yildiz, Z. I., & Uyar, T. (2018a). Electrospun nanofibers from cyclodextrin inclusion  
 1234 complexes with cineole and p-cymene: enhanced water solubility and thermal stability. *International*  
 1235 *Journal of Food Science and Technology*, 53(1), 112–120. <https://doi.org/10.1111/ijfs.13564>  
 1236 Celebioglu, A., Yildiz, Z. I., & Uyar, T. (2018b). Fabrication of Electrospun Eugenol/Cyclodextrin Inclusion  
 1237 Complex Nanofibrous Webs for Enhanced Antioxidant Property, Water Solubility, and High  
 1238 Temperature Stability. *Journal of Agricultural and Food Chemistry*, 66(2), 457–466.  
 1239 <https://doi.org/10.1021/acs.jafc.7b04312>  
 1240 Celebioglu, A., Yildiz, Z. I., & Uyar, T. (2018c). Thymol/cyclodextrin inclusion complex nanofibrous webs:

Enhanced water solubility, high thermal stability and antioxidant property of thymol. *Food Research International*, 106(December 2017), 280–290. <https://doi.org/10.1016/j.foodres.2017.12.062>

Celli, G. B., Ghanem, A., & Brooks, M. S. L. (2015). Bioactive Encapsulated Powders for Functional Foods—a Review of Methods and Current Limitations. In *Food and Bioprocess Technology* (Vol. 8, Issue 9, pp. 1825–1837). Springer New York LLC. <https://doi.org/10.1007/s11947-015-1559-z>

Chae, H. H., Kim, B. H., Yang, K. S., & Rhee, J. Il. (2011). Synthesis and antibacterial performance of size-tunable silver nanoparticles with electrospun nanofiber composites. *Synthetic Metals*, 161(19–20), 2124–2128. <https://doi.org/10.1016/j.synthmet.2011.08.013>

Cheirsilp, B., & Rakmai, J. (2017). Inclusion complex formation of cyclodextrin with its guest and their applications. *Biology, Engineering and Medicine*, 2(1). <https://doi.org/10.15761/bem.1000108>

Chen, G., & Jiang, M. (2011). Cyclodextrin-based inclusion complexation bridging supramolecular chemistry and macromolecular self-assembly. In *Chemical Society Reviews* (Vol. 40, Issue 5, pp. 2254–2266). The Royal Society of Chemistry. <https://doi.org/10.1039/c0cs00153h>

Chen, M., Nielsen, S. R., Uyar, T., Zhang, S., Zafar, A., Dong, M., & Besenbacher, F. (2013). Electrospun UV-responsive supramolecular nanofibers from a cyclodextrin-azobenzene inclusion complex. *Journal of Materials Chemistry C*, 1(4), 850–855. <https://doi.org/10.1039/c2tc00180b>

Chen, Yajun, Mensah, A., Wang, Q., Li, D., Qiu, Y., & Wei, Q. (2020). Hierarchical porous nanofibers containing thymol/beta-cyclodextrin: Physico-chemical characterization and potential biomedical applications. *Materials Science and Engineering C*, 115, 111155. <https://doi.org/10.1016/j.msec.2020.111155>

Chen, Yu, Ma, Y., Lu, W., Guo, Y., Zhu, Y., Lu, H., & Song, Y. (2018). Environmentally friendly gelatin/β-cyclodextrin composite fiber adsorbents for the efficient removal of dyes from wastewater. *Molecules*, 23(10). <https://doi.org/10.3390/molecules23102473>

Cheng, H., Yang, X., Che, X., Yang, M., & Zhai, G. (2018). Biomedical application and controlled drug release of electrospun fibrous materials. In *Materials Science and Engineering C* (Vol. 90, pp. 750–763). Elsevier Ltd. <https://doi.org/10.1016/j.msec.2018.05.007>

Chou, S. F., Carson, D., & Woodrow, K. A. (2015). Current strategies for sustaining drug release from electrospun nanofibers. In *Journal of Controlled Release* (Vol. 220, pp. 584–591). Elsevier B.V.

1269 <https://doi.org/10.1016/j.jconrel.2015.09.008>

1270 Colby, R. H. (2010). Structure and linear viscoelasticity of flexible polymer solutions: comparison of  
 1271 polyelectrolyte and neutral polymer solutions. *Rheologica Acta*, 49(5), 425–442.  
 1272 <https://doi.org/10.1007/s00397-009-0413-5>

1273 Costoya, A., Concheiro, A., & Alvarez-Lorenzo, C. (2017). Electrospun fibers of cyclodextrins and  
 1274 poly(cyclodextrins). *Molecules*, 22(2). <https://doi.org/10.3390/molecules22020230>

1275 Crini, G. (2014). Review: A history of cyclodextrins. *Chemical Reviews*, 114(21), 10940–10975.  
 1276 <https://doi.org/10.1021/cr500081p>

1277 Crini, G., Fourmentin, S., Fenyvesi, É., Torri, G., Fourmentin, M., & Morin-Crini, N. (2018). Cyclodextrins,  
 1278 from molecules to applications. In *Environmental Chemistry Letters* (Vol. 16, Issue 4, pp. 1361–1375).  
 1279 Springer Verlag. <https://doi.org/10.1007/s10311-018-0763-2>

1280 Cui, H., Zhang, C., Li, C., & Lin, L. (2019). Preparation and antibacterial activity of Litsea cubeba essential  
 1281 oil/dandelion polysaccharide nanofiber. *Industrial Crops and Products*, 140(July), 111739.  
 1282 <https://doi.org/10.1016/j.indcrop.2019.111739>

1283 DeFrates, K., Moore, R., Borgesi, J., Lin, G., Mulderig, T., Beachley, V., & Hu, X. (2018). Protein-Based  
 1284 Fiber Materials in Medicine: A Review. *Nanomaterials*, 8(7), 457.  
 1285 <https://doi.org/10.3390/nano8070457>

1286 Del Valle, E. M. M. (2004). Cyclodextrins and their uses: A review. In *Process Biochemistry* (Vol. 39, Issue  
 1287 9, pp. 1033–1046). Elsevier. [https://doi.org/10.1016/S0032-9592\(03\)00258-9](https://doi.org/10.1016/S0032-9592(03)00258-9)

1288 Dias Antunes, M., da Silva Dannenberg, G., Fiorentini, Â. M., Pinto, V. Z., Lim, L. T., da Rosa Zavareze, E.,  
 1289 & Dias, A. R. G. (2017). Antimicrobial electrospun ultrafine fibers from zein containing eucalyptus  
 1290 essential oil/cyclodextrin inclusion complex. *International Journal of Biological Macromolecules*, 104,  
 1291 874–882. <https://doi.org/10.1016/j.ijbiomac.2017.06.095>

1292 Ding, J., Zhang, J., Li, J., Li, D., Xiao, C., Xiao, H., Yang, H., Zhuang, X., & Chen, X. (2019). Electrospun  
 1293 polymer biomaterials. *Progress in Polymer Science*, 90, 1–34.  
 1294 <https://doi.org/10.1016/j.progpolymsci.2019.01.002>

1295 Dodero, A., Alloisio, M., Castellano, M., & Vicini, S. (2020). Multilayer Alginate-Polycaprolactone  
 1296 Electrospun Membranes as Skin Wound Patches with Drug Delivery Abilities. *ACS Applied Materials*

1297 *and Interfaces*, 12(28), 31162–31171. <https://doi.org/10.1021/acsami.0c07352>

1298 Dodero, A., Alloisio, M., Vicini, S., & Castellano, M. (2020). Preparation of composite alginate-based  
 1299 electrospun membranes loaded with ZnO nanoparticles. *Carbohydrate Polymers*, 227, 115371.  
 1300 <https://doi.org/10.1016/j.carbpol.2019.115371>

1301 Dodero, A., Brunengo, E., Alloisio, M., Sionkowska, A., Vicini, S., & Castellano, M. (2020). Chitosan-based  
 1302 electrospun membranes: effects of solution viscosity, coagulant and crosslinker. *Carbohydrate*  
 1303 *Polymers*, 235, 115976. <https://doi.org/10.1016/j.carbpol.2020.115976>

1304 Dodero, A., Brunengo, E., Castellano, M., & Vicini, S. (2020). Investigation of the Mechanical and  
 1305 Dynamic-Mechanical Properties of Electrospun Polyvinylpyrrolidone Membranes: A Design of  
 1306 Experiment Approach. *Polymers*, 12(7), 1524. <https://doi.org/10.3390/polym12071524>

1307 Dodero, A., Donati, I., Scarfi, S., Mirata, S., Alberti, S., Lova, P., Comoretto, D., Alloisio, M., Vicini, S., &  
 1308 Castellano, M. (2021). Effect of sodium alginate molecular structure on electrospun membrane cell  
 1309 adhesion. *Materials Science and Engineering: C*, 112067. <https://doi.org/10.1016/j.msec.2021.112067>

1310 Dodero, A., Lova, P., Vicini, S., Castellano, M., & Comoretto, D. (2020). Sodium alginate cross-linkable  
 1311 planar 1d photonic crystals as a promising tool for Pb<sup>2+</sup> detection in water. *Chemosensors*, 8(2), 37.  
 1312 <https://doi.org/https://doi.org/10.3390/chemosensors8020037>

1313 Dodero, A., Pianella, L., Vicini, S., Alloisio, M., Ottonelli, M., & Castellano, M. (2019). Alginate-based  
 1314 hydrogels prepared via ionic gelation: An experimental design approach to predict the crosslinking  
 1315 degree. *European Polymer Journal*, 118, 586–594. <https://doi.org/10.1016/j.eurpolymj.2019.06.028>

1316 Dodero, A., Scarfi, S., Mirata, S., Sionkowska, A., Vicini, S., Alloisio, M., & Castellano, M. (2021). Effect  
 1317 of Crosslinking Type on the Physical-Chemical Properties and Biocompatibility of Chitosan-Based  
 1318 Electrospun Membranes. *Polymers 2021, Vol. 13, Page 831*, 13(5), 831.  
 1319 <https://doi.org/10.3390/polym13050831>

1320 Dodero, A., Scarfi, S., Pozzolini, M., Vicini, S., Alloisio, M., & Castellano, M. (2020). Alginate-Based  
 1321 Electrospun Membranes Containing ZnO Nanoparticles as Potential Wound Healing Patches:  
 1322 Biological, Mechanical, and Physicochemical Characterization. *ACS Applied Materials and Interfaces*,  
 1323 12(3), 3371–3381. <https://doi.org/10.1021/acsami.9b17597>

1324 Dodero, A., Vicini, S., Alloisio, M., & Castellano, M. (2019). Sodium alginate solutions: correlation between

1325 rheological properties and spinnability. *Journal of Materials Science*, 54(10), 8034–8046.  
 1326 <https://doi.org/10.1007/s10853-019-03446-3>

1327 Dodero, A., Vicini, S., Alloisio, M., & Castellano, M. (2020). Rheological properties of sodium alginate  
 1328 solutions in the presence of added salt: an application of Kulicke equation. *Rheologica Acta*, 59(6).  
 1329 <https://doi.org/10.1007/s00397-020-01206-8>

1330 Dodero, A., Vicini, S., & Castellano, M. (2020). Depolymerization of sodium alginate in saline solutions via  
 1331 ultrasonic treatments: A rheological characterization. *Food Hydrocolloids*, 109, 106128.  
 1332 <https://doi.org/10.1016/j.foodhyd.2020.106128>

1333 Dodero, A., Vicini, S., Lova, P., Alloisio, M., & Castellano, M. (2020). Nanocomposite alginate-based  
 1334 electrospun membranes as novel adsorbent systems. *International Journal of Biological*  
 1335 *Macromolecules*, 165, 1939–1948. <https://doi.org/10.1016/j.ijbiomac.2020.10.116>

1336 Dodero, A., Williams, R., Gagliardi, S., Vicini, S., Alloisio, M., & Castellano, M. (2019). A micro-  
 1337 rheological and rheological study of biopolymers solutions: Hyaluronic acid. *Carbohydrate Polymers*,  
 1338 203, 349–355. <https://doi.org/10.1016/j.carbpol.2018.09.072>

1339 Dogan, Y. E., Satilmis, B., & Uyar, T. (2019). Crosslinked PolyCyclodextrin/PolyBenzoxazine electrospun  
 1340 microfibers for selective removal of methylene blue from an aqueous system. *European Polymer*  
 1341 *Journal*, 119(June), 311–321. <https://doi.org/10.1016/j.eurpolymj.2019.08.005>

1342 dos Santos, C., Buera, P., & Mazzobre, F. (2017). Novel trends in cyclodextrins encapsulation. Applications  
 1343 in food science. In *Current Opinion in Food Science* (Vol. 16, pp. 106–113). Elsevier Ltd.  
 1344 <https://doi.org/10.1016/j.cofs.2017.09.002>

1345 Fallacara, A., Baldini, E., Manfredini, S., & Vertuani, S. (2018). Hyaluronic acid in the third millennium. In  
 1346 *Polymers* (Vol. 10, Issue 7, p. 701). MDPI AG. <https://doi.org/10.3390/polym10070701>

1347 Fenyvesi, É., Vikmon, M., & Szenté, L. (2016). Cyclodextrins in Food Technology and Human Nutrition:  
 1348 Benefits and Limitations. *Critical Reviews in Food Science and Nutrition*, 56(12), 1981–2004.  
 1349 <https://doi.org/10.1080/10408398.2013.809513>

1350 Fenyvesi, Éva, Barkács, K., Gruiz, K., Varga, E., Kenyeres, I., Zárny, G., & Szenté, L. (2020). Removal of  
 1351 hazardous micropollutants from treated wastewater using cyclodextrin bead polymer – A pilot  
 1352 demonstration case. *Journal of Hazardous Materials*, 383, 121181.



1353 <https://doi.org/10.1016/j.jhazmat.2019.121181>

1354 Figueiredo, M. P., Layrac, G., Hébraud, A., Limousy, L., Brendle, J., Schlatter, G., & Constantino, V. R. L.  
 1355 (2020). Design of 3D multi-layered electrospun membranes embedding iron-based layered double  
 1356 hydroxide for drug storage and control of sustained release. *European Polymer Journal*, 131, 109675.  
 1357 <https://doi.org/10.1016/j.eurpolymj.2020.109675>

1358 Folch-Cano, C., Yazdani-Pedram, M., & Olea-Azar, C. (2014). Inclusion and Functionalization of Polymers  
 1359 with Cyclodextrins: Current Applications and Future Prospects. *Molecules*, 19(9), 14066–14079.  
 1360 <https://doi.org/10.3390/molecules190914066>

1361 Frömming, K.-H., & Szejtli, J. (1994). *Cyclodextrins* (pp. 1–18). [https://doi.org/10.1007/978-94-015-8277-](https://doi.org/10.1007/978-94-015-8277-3_1)  
 1362 [3\\_1](https://doi.org/10.1007/978-94-015-8277-3_1)

1363 Fuenmayor, C. A., Mascheroni, E., Cosio, M. S., Piergiovanni, L., Benedetti, S., Ortenzi, M., Schiraldi, A.,  
 1364 & Mannino, S. (2013). Encapsulation of R-(+)-limonene in edible electrospun nanofibers. *Chemical*  
 1365 *Engineering Transactions*, 32(May 2014), 1771–1776. <https://doi.org/10.3303/CET1332296>

1366 Galiano, F., Briceño, K., Marino, T., Molino, A., Christensen, K. V., & Figoli, A. (2018). Advances in  
 1367 biopolymer-based membrane preparation and applications. *Journal of Membrane Science*, 564, 562–  
 1368 586. <https://doi.org/10.1016/j.memsci.2018.07.059>

1369 Gao, S., Liu, Y., Jiang, J., Li, X., Zhao, L., Fu, Y., & Ye, F. (2020). Encapsulation of thiabendazole in  
 1370 hydroxypropyl-  $\beta$  - cyclodextrin nanofibers via polymer- free electrospinning and its characterization.  
 1371 *Pest Management Science*, 76(9), 3264–3272. <https://doi.org/10.1002/ps.5885>

1372 Ge, L., Zhao, Y. S., Mo, T., Li, J. R., & Li, P. (2012). Immobilization of glucose oxidase in electrospun  
 1373 nanofibrous membranes for food preservation. *Food Control*, 26(1), 188–193.  
 1374 <https://doi.org/10.1016/j.foodcont.2012.01.022>

1375 Ghorani, B., Kakhodaee, R., Rajabzadeh, G., & Tucker, N. (2019). Assembly of odour adsorbent  
 1376 nanofilters by incorporating cyclodextrin molecules into electrospun cellulose acetate webs. *Reactive*  
 1377 *and Functional Polymers*, 134(November 2018), 121–132.  
 1378 <https://doi.org/10.1016/j.reactfunctpolym.2018.11.014>

1379 Grandelli, H. E., Stickle, B., Whittington, A., & Kiran, E. (2013). Inclusion complex formation of  $\beta$ -  
 1380 cyclodextrin and Naproxen: A study on exothermic complex formation by differential scanning

calorimetry. *Journal of Inclusion Phenomena and Macrocyclic Chemistry*, 77(1–4), 269–277.  
<https://doi.org/10.1007/s10847-012-0241-6>

Guan, X., Lv, X., Huang, K., Li, S., Liu, J., Yan, Y., & Duan, R. (2019). Adsorption of Cu(II) ion by a novel hordein electrospun nanofiber modified by  $\beta$ -cyclodextrin. *International Journal of Biological Macromolecules*, 135, 691–697. <https://doi.org/10.1016/j.ijbiomac.2019.05.107>

Guo, H., Zhang, W., Jiang, Y., Wang, H., Chen, G., & Guo, M. (2019). Physicochemical, Structural, and Biological Properties of Polysaccharides from Dandelion. *Molecules*, 24(8), 1485.  
<https://doi.org/10.3390/molecules24081485>

Hall Barrientos, I. J., Paladino, E., Brozio, S., Passarelli, M. K., Moug, S., Black, R. A., Wilson, C. G., & Lamprou, D. A. (2017). Fabrication and characterisation of drug-loaded electrospun polymeric nanofibers for controlled release in hernia repair. *International Journal of Pharmaceutics*, 517(1–2), 329–337. <https://doi.org/10.1016/j.ijpharm.2016.12.022>

Hamed, I., Özogul, F., & Regenstein, J. M. (2016). Industrial applications of crustacean by-products (chitin, chitosan, and chitooligosaccharides): A review. In *Trends in Food Science and Technology* (Vol. 48, pp. 40–50). Elsevier Ltd. <https://doi.org/10.1016/j.tifs.2015.11.007>

Hamsici, S., Cinar, G., Celebioglu, A., Uyar, T., Tekinay, A. B., & Guler, M. O. (2017). Bioactive peptide functionalized aligned cyclodextrin nanofibers for neurite outgrowth. *Journal of Materials Chemistry B*, 5(3), 517–524. <https://doi.org/10.1039/c6tb02441f>

Han, W. H., Wang, Y. Z., Su, J. M., Xin, X., Guo, Y. Da, Long, Y. Z., & Ramakrishna, S. (2019). Fabrication of nanofibrous sensors by electrospinning. In *Science China Technological Sciences* (Vol. 62, Issue 6, pp. 886–894). Springer Verlag. <https://doi.org/10.1007/s11431-018-9405-5>

He, Y., Hou, X., Liu, Y., & Feng, N. (2019). Recent progress in the synthesis, structural diversity and emerging applications of cyclodextrin-based metal-organic frameworks. In *Journal of Materials Chemistry B* (Vol. 7, Issue 37, pp. 5602–5619). Royal Society of Chemistry.  
<https://doi.org/10.1039/c9tb01548e>

Heydari, A., Mehrabi, F., Shamspur, T., Sheibani, H., & Mostafavi, A. (2018). Encapsulation and Controlled Release of Vitamin B2 Using Peracetyl- $\beta$ -Cyclodextrin Polymer-Based Electrospun Nanofiber Scaffold. *Pharmaceutical Chemistry Journal*, 52(1), 19–25. <https://doi.org/10.1007/s11094-018-1759-8>

1409 Hosseini, S. F., & Gómez-Guillén, M. C. (2018). A state-of-the-art review on the elaboration of fish gelatin  
 1410 as bioactive packaging: Special emphasis on nanotechnology-based approaches. In *Trends in Food*  
 1411 *Science and Technology* (Vol. 79, pp. 125–135). Elsevier Ltd. <https://doi.org/10.1016/j.tifs.2018.07.022>  
 1412 Huang, X. J., Ge, D., & Xu, Z. K. (2007). Preparation and characterization of stable chitosan nanofibrous  
 1413 membrane for lipase immobilization. *European Polymer Journal*, 43(9), 3710–3718.  
 1414 <https://doi.org/10.1016/j.eurpolymj.2007.06.010>  
 1415 Huang, X., Kanerva, P., Salovaara, H., Stoddard, F. L., & Sontag-Strohm, T. (2017). Proposal for C-Hordein  
 1416 as Reference Material in Gluten Quantification. *Journal of Agricultural and Food Chemistry*, 65(10),  
 1417 2155–2161. <https://doi.org/10.1021/acs.jafc.6b05061>  
 1418 Ismail, N., Junior Maksoud, F., Ghaddar, N., Ghali, K., & Tehrani-Bagha, A. (2017). A mathematical model  
 1419 to predict the effect of electrospinning processing parameters on the morphological characteristic of  
 1420 nano-fibrous web and associated filtration efficiency. *Journal of Aerosol Science*, 113, 227–241.  
 1421 <https://doi.org/10.1016/j.jaerosci.2017.08.013>  
 1422 Jansook, P., Ogawa, N., & Loftsson, T. (2018). Cyclodextrins: structure, physicochemical properties and  
 1423 pharmaceutical applications. *International Journal of Pharmaceutics*, 535(1–2), 272–284.  
 1424 <https://doi.org/10.1016/j.ijpharm.2017.11.018>  
 1425 Jia, F., Zhang, C., Wang, Q., Li, J., Chen, Y., & Wang, J. (2020). Physicochemical and structural  
 1426 characteristics of the Venn components of wheat gliadin. *Grain & Oil Science and Technology*, 3(1),  
 1427 18–24. <https://doi.org/10.1016/j.gaost.2020.01.003>  
 1428 Kadam, V., Truong, Y. B., Schutz, J., Kyratzis, I. L., Padhye, R., & Wang, L. (2021). Gelatin/β–  
 1429 Cyclodextrin Bio–Nanofibers as respiratory filter media for filtration of aerosols and volatile organic  
 1430 compounds at low air resistance. *Journal of Hazardous Materials*, 403, 123841.  
 1431 <https://doi.org/10.1016/j.jhazmat.2020.123841>  
 1432 Kakoria, A., & Sinha-Ray, S. (2018). A Review on Biopolymer-Based Fibers via Electrospinning and  
 1433 Solution Blowing and Their Applications. *Fibers*, 6(3), 45. <https://doi.org/10.3390/fib6030045>  
 1434 Kannan, B., Cha, H., & Hosie, I. C. (2016). Electrospinning—commercial applications, challenges and  
 1435 opportunities. In *Nano-Size Polymers: Preparation, Properties, Applications* (pp. 309–342). Springer  
 1436 International Publishing. [https://doi.org/10.1007/978-3-319-39715-3\\_11](https://doi.org/10.1007/978-3-319-39715-3_11)

1437 Karayannakidis, P. D., & Zotos, A. (2016). Fish Processing By-Products as a Potential Source of Gelatin: A  
 1438 Review. In *Journal of Aquatic Food Product Technology* (Vol. 25, Issue 1, pp. 65–92). Taylor and  
 1439 Francis Inc. <https://doi.org/10.1080/10498850.2013.827767>

1440 Kasaai, M. R. (2017). Zein and Zein-Based Nanoparticles for Food Packaging Applications: A Global View.  
 1441 *Advanced Science, Engineering and Medicine*, 9(6), 439–444. <https://doi.org/10.1166/asem.2017.2025>

1442 Kayaci, F., Aytac, Z., & Uyar, T. (2013). Surface modification of electrospun polyester nanofibers with  
 1443 cyclodextrin polymer for the removal of phenanthrene from aqueous solution. *Journal of Hazardous*  
 1444 *Materials*, 261, 286–294. <https://doi.org/10.1016/j.jhazmat.2013.07.041>

1445 Kayaci, F., Ertas, Y., & Uyar, T. (2013). Enhanced thermal stability of eugenol by cyclodextrin inclusion  
 1446 complex encapsulated in electrospun polymeric nanofibers. *Journal of Agricultural and Food*  
 1447 *Chemistry*, 61(34), 8156–8165. <https://doi.org/10.1021/jf402923c>

1448 Kayaci, F., Sen, H. S., Durgun, E., & Uyar, T. (2015). Electrospun nylon 6,6 nanofibers functionalized with  
 1449 cyclodextrins for removal of toluene vapor. *Journal of Applied Polymer Science*, 132(18), 34–37.  
 1450 <https://doi.org/10.1002/app.41941>

1451 Kayaci, F., Umu, O. C. O., Tekinay, T., & Uyar, T. (2013). Antibacterial electrospun poly(lactic acid) (PLA)  
 1452 nanofibrous webs incorporating triclosan/cyclodextrin inclusion complexes. *Journal of Agricultural*  
 1453 *and Food Chemistry*, 61(16), 3901–3908. <https://doi.org/10.1021/jf400440b>

1454 Kayaci, F., & Uyar, T. (2012a). Electrospun zein nanofibers incorporating cyclodextrins. *Carbohydrate*  
 1455 *Polymers*, 90(1), 558–568. <https://doi.org/10.1016/j.carbpol.2012.05.078>

1456 Kayaci, F., & Uyar, T. (2012b). Encapsulation of vanillin/cyclodextrin inclusion complex in electrospun  
 1457 polyvinyl alcohol (PVA) nanowebs: Prolonged shelf-life and high temperature stability of vanillin.  
 1458 *Food Chemistry*, 133(3), 641–649. <https://doi.org/10.1016/j.foodchem.2012.01.040>

1459 Kersani, D., Mougín, J., Lopez, M., Degoutin, S., Tabary, N., Cazaux, F., Janus, L., Maton, M., Chai, F.,  
 1460 Sobocinski, J., Blanchemain, N., & Martel, B. (2020). Stent coating by electrospinning with  
 1461 chitosan/poly-cyclodextrin based nanofibers loaded with simvastatin for restenosis prevention.  
 1462 *European Journal of Pharmaceutics and Biopharmaceutics*, 150(September 2019), 156–167.  
 1463 <https://doi.org/10.1016/j.ejpb.2019.12.017>

1464 Kim, H., Jeong, K., Park, H., & Jung, S. (2006). Preference prediction for the stable inclusion complexes

1465 between cyclodextrins and monocyclic insoluble chemicals based on Monte Carlo docking simulations.  
 1466 *Journal of Inclusion Phenomena*, 54(3–4), 165–170. <https://doi.org/10.1007/s10847-005-6288-x>  
 1467 Kiss, K., Vass, P., Farkas, A., Hirsch, E., Szabó, E., Mező, G., Nagy, Z. K., & Marosi, G. (2020). A solid  
 1468 doxycycline HP- $\beta$ -CD formulation for reconstitution (i.v. bolus) prepared by scaled-up electrospinning.  
 1469 *International Journal of Pharmaceutics*, 586, 119539. <https://doi.org/10.1016/j.ijpharm.2020.119539>  
 1470 Koh, L. D., Yeo, J., Lee, Y. Y., Ong, Q., Han, M., & Tee, B. C. K. (2018). Advancing the frontiers of silk  
 1471 fibroin protein-based materials for futuristic electronics and clinical wound-healing (Invited review). In  
 1472 *Materials Science and Engineering C* (Vol. 86, pp. 151–172). Elsevier Ltd.  
 1473 <https://doi.org/10.1016/j.msec.2018.01.007>  
 1474 Kurkov, S. V., & Loftsson, T. (2013). Cyclodextrins. In *International Journal of Pharmaceutics* (Vol. 453,  
 1475 Issue 1, pp. 167–180). Elsevier B.V. <https://doi.org/10.1016/j.ijpharm.2012.06.055>  
 1476 Landy, D., Mallard, I., Ponchel, A., Monflier, E., & Fourmentin, S. (2012). Remediation technologies using  
 1477 cyclodextrins: An overview. In *Environmental Chemistry Letters* (Vol. 10, Issue 3, pp. 225–237).  
 1478 Springer. <https://doi.org/10.1007/s10311-011-0351-1>  
 1479 Li, J., He, A., Han, C. C., Fang, D., Hsiao, B. S., & Chu, B. (2006). Electrospinning of Hyaluronic Acid  
 1480 (HA) and HA/Gelatin Blends. *Macromolecular Rapid Communications*, 27(2), 114–120.  
 1481 <https://doi.org/10.1002/marc.200500726>  
 1482 Li, L., & Hsieh, Y. Lo. (2005). Ultra-fine polyelectrolyte fibers from electrospinning of poly(acrylic acid).  
 1483 *Polymer*, 46(14), 5133–5139. <https://doi.org/10.1016/j.polymer.2005.04.039>  
 1484 Li, R., Dou, J., Jiang, Q., Li, J., Xie, Z., Liang, J., & Ren, X. (2014). Preparation and antimicrobial activity of  
 1485  $\beta$ -cyclodextrin derivative copolymers/cellulose acetate nanofibers. *Chemical Engineering Journal*, 248,  
 1486 264–272. <https://doi.org/10.1016/j.cej.2014.03.042>  
 1487 Li, S., & Purdy, W. C. (1992). Cyclodextrins and Their Applications in Analytical Chemistry. *Chemical*  
 1488 *Reviews*, 92(6), 1457–1470. <https://doi.org/10.1021/cr00014a009>  
 1489 Lin, L., Dai, Y., & Cui, H. (2017). Antibacterial poly(ethylene oxide) electrospun nanofibers containing  
 1490 cinnamon essential oil/beta-cyclodextrin proteoliposomes. *Carbohydrate Polymers*, 178(September),  
 1491 131–140. <https://doi.org/10.1016/j.carbpol.2017.09.043>  
 1492 Liu, Q., Zhou, Y., Lu, J., & Zhou, Y. (2020a). Novel cyclodextrin-based adsorbents for removing pollutants

1493 from wastewater: A critical review. *Chemosphere*, 241, 125043.  
 1494 <https://doi.org/10.1016/j.chemosphere.2019.125043>

1495 Liu, Q., Zhou, Y., Lu, J., & Zhou, Y. (2020b). Novel cyclodextrin-based adsorbents for removing pollutants  
 1496 from wastewater: A critical review. In *Chemosphere* (Vol. 241, p. 125043). Elsevier Ltd.  
 1497 <https://doi.org/10.1016/j.chemosphere.2019.125043>

1498 Liu, W., Wang, Y., Yao, J., Shao, Z., & Chen, X. (2016). Tamoxifen-loaded silk fibroin electrospun fibers.  
 1499 *Materials Letters*, 178, 31–34. <https://doi.org/10.1016/j.matlet.2016.04.177>

1500 Liu, Y., Liang, X., Zhang, R., Lan, W., & Qin, W. (2017). Fabrication of electrospun polylactic  
 1501 acid/Cinnamaldehyde/ $\beta$ -cyclodextrin fibers as an antimicrobial wound dressing. *Polymers*, 9(10).  
 1502 <https://doi.org/10.3390/polym9100464>

1503 Lohith Kumar, D. H., & Sarkar, P. (2018). Encapsulation of bioactive compounds using nanoemulsions. In  
 1504 *Environmental Chemistry Letters* (Vol. 16, Issue 1, pp. 59–70). Springer Verlag.  
 1505 <https://doi.org/10.1007/s10311-017-0663-x>

1506 Lova, P., Manfredi, G., Bastianini, C., Mennucci, C., Buatier De Mongeot, F., Servida, A., & Comoretto, D.  
 1507 (2019). Flory-Huggins Photonic Sensors for the Optical Assessment of Molecular Diffusion  
 1508 Coefficients in Polymers. *ACS Applied Materials and Interfaces*, 11(18), 16872–16880.  
 1509 <https://doi.org/10.1021/acsami.9b03946>

1510 Lova, P., Manfredi, G., & Comoretto, D. (2018). Advances in Functional Solution Processed Planar 1D  
 1511 Photonic Crystals. *Advanced Optical Materials*, 6(24), 1800730.  
 1512 <https://doi.org/10.1002/adom.201800730>

1513 Lukáš, D., Sarkar, A., Martinová, L., Vodsed'álková, K., Lubasová, D., Chaloupek, J., Pokorný, P., Mikeš,  
 1514 P., Chvojka, J., & Komárek, M. (2009). Physical principles of electrospinning (Electrospinning as a  
 1515 nano-scale technology of the twenty-first century). *Textile Progress*, 41(2), 59–140.  
 1516 <https://doi.org/10.1080/00405160902904641>

1517 Lv, D., Zhu, M., Jiang, Z., Jiang, S., Zhang, Q., Xiong, R., & Huang, C. (2018). Green Electrospun  
 1518 Nanofibers and Their Application in Air Filtration. *Macromolecular Materials and Engineering*,  
 1519 303(12), 1800336. <https://doi.org/10.1002/mame.201800336>

1520 Lv, Y., Ma, J., Liu, K., Jiang, Y., Yang, G., Liu, Y., Lin, C., Ye, X., Shi, Y., Liu, M., & Chen, L. (2021).

1521 Rapid elimination of trace bisphenol pollutants with porous  $\beta$ -cyclodextrin modified cellulose  
 1522 nanofibrous membrane in water: adsorption behavior and mechanism. *Journal of Hazardous Materials*,  
 1523 403, 123666. <https://doi.org/10.1016/j.jhazmat.2020.123666>

1524 Manasco, J. L., Saquing, C. D., Tang, C., & Khan, S. A. (2012). Cyclodextrin fibers via polymer-free  
 1525 electrospinning. *RSC Advances*, 2(9), 3778–3784. <https://doi.org/10.1039/c2ra00004k>

1526 Mascheroni, E., Fuenmayor, C. A., Cosio, M. S., Silvestro, G. Di, Piergiovanni, L., Mannino, S., & Schiraldi,  
 1527 A. (2013). Encapsulation of volatiles in nanofibrous polysaccharide membranes for humidity-triggered  
 1528 release. *Carbohydrate Polymers*, 98(1), 17–25. <https://doi.org/10.1016/j.carbpol.2013.04.068>

1529 Matencio, A., Navarro-Orcajada, S., García-Carmona, F., & López-Nicolás, J. M. (2020). Applications of  
 1530 cyclodextrins in food science. A review. *Trends in Food Science and Technology*, 104, 132–143.  
 1531 <https://doi.org/10.1016/j.tifs.2020.08.009>

1532 McKee, M. G., Layman, J. M., Cashion, M. P., & Long, T. E. (2006). Phospholipid nonwoven electrospun  
 1533 membranes. *Science*, 311(5759), 353–355. <https://doi.org/10.1126/science.1119790>

1534 Meinel, A. J., Germershaus, O., Luhmann, T., Merkle, H. P., & Meinel, L. (2012). Electrospun matrices for  
 1535 localized drug delivery: Current technologies and selected biomedical applications. In *European*  
 1536 *Journal of Pharmaceutics and Biopharmaceutics* (Vol. 81, Issue 1, pp. 1–13). Elsevier.  
 1537 <https://doi.org/10.1016/j.ejpb.2012.01.016>

1538 Mendes, A. C., Stephansen, K., & Chronakis, I. S. (2017). Electrospinning of food proteins and  
 1539 polysaccharides. *Food Hydrocolloids*, 68, 53–68. <https://doi.org/10.1016/j.foodhyd.2016.10.022>

1540 Miguel, S. P., Figueira, D. R., Simões, D., Ribeiro, M. P., Coutinho, P., Ferreira, P., & Correia, I. J. (2018).  
 1541 Electrospun polymeric nanofibres as wound dressings: A review. In *Colloids and Surfaces B:*  
 1542 *Biointerfaces* (Vol. 169, pp. 60–71). Elsevier B.V. <https://doi.org/10.1016/j.colsurfb.2018.05.011>

1543 Mirjalili, M., & Zohoori, S. (2016). Review for application of electrospinning and electrospun nanofibers  
 1544 technology in textile industry. *Journal of Nanostructure in Chemistry*, 6(3), 207–213.  
 1545 <https://doi.org/10.1007/s40097-016-0189-y>

1546 Mohanty, J., Bhasikuttan, A. C., Nail, W. M., & Pal, H. (2006). Host-guest complexation of neutral red with  
 1547 macrocyclic host molecules: Contrasting pKa shifts and binding affinities for cucurbit[7]uril and  $\beta$ -  
 1548 cyclodextrin. *Journal of Physical Chemistry B*, 110(10), 5132–5138. <https://doi.org/10.1021/jp056411p>

1549 Morin-Crini, N., & Crini, G. (2013). Environmental applications of water-insoluble  $\beta$ -cyclodextrin-  
 1550 epichlorohydrin polymers. In *Progress in Polymer Science* (Vol. 38, Issue 2, pp. 344–368). Pergamon.  
 1551 <https://doi.org/10.1016/j.progpolymsci.2012.06.005>

1552 Moyers-Montoya, E., García-Casillas, P., Vargas-Requena, C., Escobedo-González, R., Martel-Estrada, S.-  
 1553 A., & Martínez-Pérez, C. (2016). Polycaprolactone/Amino- $\beta$ -Cyclodextrin Inclusion Complex Prepared  
 1554 by an Electrospinning Technique. *Polymers*, 8(11), 395. <https://doi.org/10.3390/polym8110395>

1555 Muiznieks, L. D., & Keeley, F. W. (2017). Biomechanical Design of Elastic Protein Biomaterials: A Balance  
 1556 of Protein Structure and Conformational Disorder. *ACS Biomaterials Science and Engineering*, 3(5),  
 1557 661–679. <https://doi.org/10.1021/acsbiomaterials.6b00469>

1558 Munhuweyi, K., Caleb, O. J., van Reenen, A. J., & Opara, U. L. (2018). Physical and antifungal properties of  
 1559  $\beta$ -cyclodextrin microcapsules and nanofibre films containing cinnamon and oregano essential oils. *LWT*  
 1560 - *Food Science and Technology*, 87, 413–422. <https://doi.org/10.1016/j.lwt.2017.09.012>

1561 Mura, P. (2015). Analytical techniques for characterization of cyclodextrin complexes in the solid state: A  
 1562 review. In *Journal of Pharmaceutical and Biomedical Analysis* (Vol. 113, pp. 226–238). Elsevier.  
 1563 <https://doi.org/10.1016/j.jpba.2015.01.058>

1564 Narayanan, G., Boy, R., Gupta, B. S., & Tonelli, A. E. (2017). Functional nanofibers containing  
 1565 cyclodextrins. In *Polysaccharide-Based Fibers and Composites: Chemical and Engineering*  
 1566 *Fundamentals and Industrial Applications* (pp. 29–62). Springer International Publishing.  
 1567 [https://doi.org/10.1007/978-3-319-56596-5\\_3](https://doi.org/10.1007/978-3-319-56596-5_3)

1568 Narayanan, G., Ormond, B. R., Gupta, B. S., & Tonelli, A. E. (2015). Efficient wound odor removal by  $\beta$ -  
 1569 cyclodextrin functionalized poly ( $\epsilon$ -caprolactone) nanofibers. *Journal of Applied Polymer Science*,  
 1570 132(45), n/a-n/a. <https://doi.org/10.1002/app.42782>

1571 Norouzi, Z., Abdouss, M., Shoushtari, A. M., Haji, A., & Branch, B. (2012). Electrospinning of  $\beta$ -  
 1572 cyclodextrine grafted chitosan. *5th Texteh International Conference, May 2014*, 275–284.

1573 Noruzi, M. (2016). Electrospun nanofibres in agriculture and the food industry: a review. *Journal of the*  
 1574 *Science of Food and Agriculture*, 96(14), 4663–4678. <https://doi.org/10.1002/jsfa.7737>

1575 Nthunya, L. N., Masheane, M. L., Malinga, S. P., Nxumalo, E. N., Barnard, T. G., Kao, M., Tetana, Z. N., &  
 1576 Mhlanga, S. D. (2017). Greener Approach to Prepare Electrospun Antibacterial  $\beta$ -



1577 Cyclodextrin/Cellulose Acetate Nanofibers for Removal of Bacteria from Water. *ACS Sustainable*  
1578 *Chemistry and Engineering*, 5(1), 153–160. <https://doi.org/10.1021/acssuschemeng.6b01089>

1579 Öner, E. T., Hernández, L., & Combie, J. (2016). Review of Levan polysaccharide: From a century of past  
1580 experiences to future prospects. In *Biotechnology Advances* (Vol. 34, Issue 5, pp. 827–844). Elsevier  
1581 Inc. <https://doi.org/10.1016/j.biotechadv.2016.05.002>

1582 Oster, M., Schlatter, G., Gallet, S., Baati, R., Pollet, E., Gaillard, C., Avérous, L., Fajolles, C., & Hébraud, A.  
1583 (2017). The study of the pseudo-polyrotaxane architecture as a route for mild surface functionalization  
1584 by click chemistry of poly( $\epsilon$ -caprolactone)-based electrospun fibers. *Journal of Materials Chemistry B*,  
1585 5(11), 2181–2189. <https://doi.org/10.1039/c6tb03089k>

1586 Oster, Murielle, Hébraud, A., Gallet, S., Lapp, A., Pollet, E., Avérous, L., & Schlatter, G. (2015). Star-  
1587 pseudopolyrotaxane organized in nanoplatelets for poly( $\epsilon$ -caprolactone)-based nanofibrous scaffolds  
1588 with enhanced surface reactivity. *Macromolecular Rapid Communications*, 36(3), 292–297.  
1589 <https://doi.org/10.1002/marc.201400533>

1590 Ouerghemmi, S., Degoutin, S., Tabary, N., Cazaux, F., Maton, M., Gaucher, V., Janus, L., Neut, C., Chai, F.,  
1591 Blanchemain, N., & Martel, B. (2016). Triclosan loaded electrospun nanofibers based on a cyclodextrin  
1592 polymer and chitosan polyelectrolyte complex. *International Journal of Pharmaceutics*, 513(1–2),  
1593 483–495. <https://doi.org/10.1016/j.ijpharm.2016.09.060>

1594 Pan, J., Ai, F., Shao, P., Chen, H., & Gao, H. (2019). Development of polyvinyl alcohol/ $\beta$ -cyclodextrin  
1595 antimicrobial nanofibers for fresh mushroom packaging. *Food Chemistry*, 300(July), 125249.  
1596 <https://doi.org/10.1016/j.foodchem.2019.125249>

1597 Patiño Vidal, C., López de Dicastillo, C., Rodríguez-Mercado, F., Guarda, A., Galotto, M. J., & Muñoz-  
1598 Shugulí, C. (2021). Electrospinning and cyclodextrin inclusion complexes: An emerging technological  
1599 combination for developing novel active food packaging materials. *Critical Reviews in Food Science*  
1600 *and Nutrition*, 1–16. <https://doi.org/10.1080/10408398.2021.1886038>

1601 Prajapati, V. D., Jani, G. K., & Khanda, S. M. (2013). Pullulan: An exopolysaccharide and its various  
1602 applications. In *Carbohydrate Polymers* (Vol. 95, Issue 1, pp. 540–549). Elsevier.  
1603 <https://doi.org/10.1016/j.carbpol.2013.02.082>

1604 Prochowicz, D., Kornowicz, A., Justyniak, I., & Lewiński, J. (2016). Metal complexes based on native

cyclodextrins: Synthesis and structural diversity. In *Coordination Chemistry Reviews* (Vol. 306, Issue P1, pp. 331–345). Elsevier. <https://doi.org/10.1016/j.ccr.2015.07.016>

Prochowicz, D., Kornowicz, A., & Lewiński, J. (2017). Interactions of Native Cyclodextrins with Metal Ions and Inorganic Nanoparticles: Fertile Landscape for Chemistry and Materials Science. *Chemical Reviews*, 117(22), 13461–13501. <https://doi.org/10.1021/acs.chemrev.7b00231>

Qi, Y., Wang, H., Wei, K., Yang, Y., Zheng, R.-Y., Kim, I., & Zhang, K.-Q. (2017). A Review of Structure Construction of Silk Fibroin Biomaterials from Single Structures to Multi-Level Structures. *International Journal of Molecular Sciences*, 18(3), 237. <https://doi.org/10.3390/ijms18030237>

Qian, Y., Qi, M., Zheng, L., King, M., Lv, L., & Ye, F. (2016). Incorporation of Rutin in Electrospun Pullulan/PVA Nanofibers for Novel UV-Resistant Properties. *Materials*, 9(7), 504. <https://doi.org/10.3390/ma9070504>

Qiu, X., & Hu, S. (2013). “Smart” Materials Based on Cellulose: A Review of the Preparations, Properties, and Applications. *Materials*, 6(3), 738–781. <https://doi.org/10.3390/ma6030738>

Quirós, J., Boltes, K., & Rosal, R. (2016). Bioactive Applications for Electrospun Fibers. In *Polymer Reviews* (Vol. 56, Issue 4, pp. 631–667). Taylor and Francis Inc. <https://doi.org/10.1080/15583724.2015.1136641>

Ramakrishna, S., Fujihara, K., Teo, W. E., Yong, T., Ma, Z., & Ramaseshan, R. (2006). Electrospun nanofibers: Solving global issues. *Materials Today*, 9(3), 40–50. [https://doi.org/10.1016/S1369-7021\(06\)71389-X](https://doi.org/10.1016/S1369-7021(06)71389-X)

Rani, S., & Kumar, R. (2019). A Review on Material and Antimicrobial Properties of Soy Protein Isolate Film. In *Journal of Polymers and the Environment* (Vol. 27, Issue 8, pp. 1613–1628). Springer New York LLC. <https://doi.org/10.1007/s10924-019-01456-5>

Rezaei, A., & Nasirpour, A. (2019). Evaluation of Release Kinetics and Mechanisms of Curcumin and Curcumin- $\beta$ -Cyclodextrin Inclusion Complex Incorporated in Electrospun Almond Gum/PVA Nanofibers in Simulated Saliva and Simulated Gastrointestinal Conditions. *BioNanoScience*, 9(2), 438–445. <https://doi.org/10.1007/s12668-019-00620-4>

Riaz Rajoka, M. S., Zhao, L., Mehwish, H. M., Wu, Y., & Mahmood, S. (2019). Chitosan and its derivatives: synthesis, biotechnological applications, and future challenges. In *Applied Microbiology and*

1633 *Biotechnology* (Vol. 103, Issue 4, pp. 1557–1571). Springer Verlag. <https://doi.org/10.1007/s00253->  
1634 018-9550-z

1635 Rivero, P. J., Urrutia, A., Goicoechea, J., & Arregui, F. J. (2015). Nanomaterials for Functional Textiles and  
1636 Fibers. In *Nanoscale Research Letters* (Vol. 10, Issue 1, pp. 1–22). Springer New York LLC.  
1637 <https://doi.org/10.1186/s11671-015-1195-6>

1638 Rozemarie Manea, L., & Berteau, A.-P. (2019). Sensors from Electrospun Nanostructures. In *Nanostructures*  
1639 *in Energy Generation, Transmission and Storage*. IntechOpen.  
1640 <https://doi.org/10.5772/intechopen.78289>

1641 Rubinstein, M., & Semenov, A. N. (2001). Dynamics of entangled solutions of associating polymers.  
1642 *Macromolecules*, 34(4), 1058–1068. <https://doi.org/10.1021/ma0013049>

1643 Sá Couto, A., Salústio, P., & Cabral-Marques, H. (2015). Cyclodextrins. In *Polysaccharides: Bioactivity and*  
1644 *Biotechnology* (pp. 247–288). Springer International Publishing. <https://doi.org/10.1007/978-3-319->  
1645 16298-0\_22

1646 Saenger, W., Jacob, J., Gessler, K., Steiner, T., Hoffmann, D., Sanbe, H., Koizumi, K., Smith, S. M., &  
1647 Takaha, T. (1998). Structures of the common cyclodextrins and their larger analogues - beyond the  
1648 doughnut. *Chemical Reviews*, 98(5), 1787–1802. <https://doi.org/10.1021/cr9700181>

1649 San Keskin, N. O., Celebioglu, A., Sarioglu, O. F., Uyar, T., & Tekinay, T. (2018). Encapsulation of living  
1650 bacteria in electrospun cyclodextrin ultrathin fibers for bioremediation of heavy metals and reactive dye  
1651 from wastewater. *Colloids and Surfaces B: Biointerfaces*, 161, 169–176.  
1652 <https://doi.org/10.1016/j.colsurfb.2017.10.047>

1653 Schiffman, J. D., & Schauer, C. L. (2008). A review: Electrospinning of biopolymer nanofibers and their  
1654 applications. *Polymer Reviews*, 48(2), 317–352. <https://doi.org/10.1080/15583720802022182>

1655 Semalty, M., Panchpuri, M., Singh, D., & Semalty, A. (2014). Cyclodextrin Inclusion Complex of  
1656 Racecadotril: Effect of Drug-&#946;- Cyclodextrin Ratio and the Method of Complexation. *Current*  
1657 *Drug Discovery Technologies*, 11(2), 154–161. <https://doi.org/10.2174/15701638113106660043>

1658 Senthil Muthu Kumar, T., Senthil Kumar, K., Rajini, N., Siengchin, S., Ayrilmis, N., & Varada Rajulu, A.  
1659 (2019). A comprehensive review of electrospun nanofibers: Food and packaging perspective.  
1660 *Composites Part B: Engineering*, 175, 107074. <https://doi.org/10.1016/j.compositesb.2019.107074>

- 1661 Séon-Lutz, M., Couffin, A. C., Vignoud, S., Schlatter, G., & Hébraud, A. (2019). Electrospinning in water  
1662 and in situ crosslinking of hyaluronic acid / cyclodextrin nanofibers: Towards wound dressing with  
1663 controlled drug release. *Carbohydrate Polymers*, 207(November 2018), 276–287.  
1664 <https://doi.org/10.1016/j.carbpol.2018.11.085>
- 1665 Sharif, N., Golmakani, M. T., Niakousari, M., Hosseini, S. M. H., Ghorani, B., & Lopez-Rubio, A. (2018).  
1666 Active food packaging coatings based on hybrid electrospun gliadin nanofibers containing ferulic  
1667 acid/hydroxypropyl-beta-cyclodextrin inclusion complexes. *Nanomaterials*, 8(11).  
1668 <https://doi.org/10.3390/nano8110919>
- 1669 Sherje, A. P., Dravyakar, B. R., Kadam, D., & Jadhav, M. (2017). Cyclodextrin-based nanosponges: A  
1670 critical review. In *Carbohydrate Polymers* (Vol. 173, pp. 37–49). Elsevier Ltd.  
1671 <https://doi.org/10.1016/j.carbpol.2017.05.086>
- 1672 Shishir, M. R. I., Xie, L., Sun, C., Zheng, X., & Chen, W. (2018). Advances in micro and nano-encapsulation  
1673 of bioactive compounds using biopolymer and lipid-based transporters. In *Trends in Food Science and*  
1674 *Technology* (Vol. 78, pp. 34–60). Elsevier Ltd. <https://doi.org/10.1016/j.tifs.2018.05.018>
- 1675 Sila, A., Bayar, N., Ghazala, I., Bougatef, A., Ellouz-Ghorbel, R., & Ellouz-Chaabouni, S. (2014). Water-  
1676 soluble polysaccharides from agro-industrial by-products: Functional and biological properties.  
1677 *International Journal of Biological Macromolecules*, 69, 236–243.  
1678 <https://doi.org/10.1016/j.ijbiomac.2014.05.052>
- 1679 Singh, N., & Sahu, O. (2018). Sustainable cyclodextrin in textile applications. In *The Impact and Prospects*  
1680 *of Green Chemistry for Textile Technology* (pp. 83–105). Elsevier. [https://doi.org/10.1016/B978-0-08-](https://doi.org/10.1016/B978-0-08-102491-1.00004-6)  
1681 [102491-1.00004-6](https://doi.org/10.1016/B978-0-08-102491-1.00004-6)
- 1682 Snowdon, M. R., & Liang, R. L. (2020). Electrospun filtration membranes for environmental remediation. In  
1683 *Nanomaterials for Air Remediation* (pp. 309–341). Elsevier. [https://doi.org/10.1016/b978-0-12-](https://doi.org/10.1016/b978-0-12-818821-7.00016-6)  
1684 [818821-7.00016-6](https://doi.org/10.1016/b978-0-12-818821-7.00016-6)
- 1685 Soares, R. M. D., Siqueira, N. M., Prabhakaram, M. P., & Ramakrishna, S. (2018). Electrospinning and  
1686 electrospray of bio-based and natural polymers for biomaterials development. *Materials Science and*  
1687 *Engineering C*, 92, 969–982. <https://doi.org/10.1016/j.msec.2018.08.004>
- 1688 Song, L. X., Bai, L., Xu, X. M., He, J., & Pan, S. Z. (2009). Inclusion complexation, encapsulation

interaction and inclusion number in cyclodextrin chemistry. In *Coordination Chemistry Reviews* (Vol. 253, Issues 9–10, pp. 1276–1284). Elsevier. <https://doi.org/10.1016/j.ccr.2008.08.011>

Szejtli, J. (1998). Introduction and general overview of cyclodextrin chemistry. *Chemical Reviews*, 98(5), 1743–1753. <https://doi.org/10.1021/cr970022c>

Tebyetekerwa, M., & Ramakrishna, S. (2020). What Is Next for Electrospinning? *Matter*, 2(2), 279–283. <https://doi.org/10.1016/j.matt.2020.01.004>

Thenmozhi, S., Dharmaraj, N., Kadirvelu, K., & Kim, H. Y. (2017). Electrospun nanofibers: New generation materials for advanced applications. *Materials Science and Engineering B: Solid-State Materials for Advanced Technology*, 217, 36–48. <https://doi.org/10.1016/j.mseb.2017.01.001>

Thompson, C. J., Chase, G. G., Yarin, A. L., & Reneker, D. H. (2007). Effects of parameters on nanofiber diameter determined from electrospinning model. *Polymer*, 48(23), 6913–6922. <https://doi.org/10.1016/j.polymer.2007.09.017>

Tian, H., Guo, G., Fu, X., Yao, Y., Yuan, L., & Xiang, A. (2018). Fabrication, properties and applications of soy-protein-based materials: A review. In *International Journal of Biological Macromolecules* (Vol. 120, pp. 475–490). Elsevier B.V. <https://doi.org/10.1016/j.ijbiomac.2018.08.110>

Tonelli, A. E. (2008). Nanostructuring and functionalizing polymers with cyclodextrins. *Polymer*, 49(7), 1725–1736. <https://doi.org/10.1016/j.polymer.2007.12.003>

Topuz, F., Kilic, M. E., Durgun, E., & Szekely, G. (2021). Fast-dissolving antibacterial nanofibers of cyclodextrin/antibiotic inclusion complexes for oral drug delivery. *Journal of Colloid and Interface Science*, 585, 184–194. <https://doi.org/10.1016/j.jcis.2020.11.072>

Topuz, F., Shaikh, A. Y., Guler, M. O., & Uyar, T. (2020). Water-insoluble polymer-free uniform nanofibers of peracetylated cyclodextrin by electrospinning. *Journal of Materials Science*, 55(25), 11752–11762. <https://doi.org/10.1007/s10853-020-04820-2>

Topuz, F., & Uyar, T. (2019). Electrospinning of cyclodextrin functional nanofibers for drug delivery applications. *Pharmaceutics*, 11(1). <https://doi.org/10.3390/pharmaceutics11010006>

Topuz, F., & Uyar, T. (2020). Electrospinning of Cyclodextrin Nanofibers: The Effect of Process Parameters. *Journal of Nanomaterials*, 2020. <https://doi.org/10.1155/2020/7529306>

Torres-Giner, S., Pérez-Masiá, R., & Lagaron, J. M. (2016). A review on electrospun polymer nanostructures

as advanced bioactive platforms. 56(5), 500–527. <https://doi.org/10.1002/pen.24274>

Turasan, H., & Kokini, J. L. (2017). Advances in Understanding the Molecular Structures and Functionalities of Biodegradable Zein-Based Materials Using Spectroscopic Techniques: A Review. *Biomacromolecules*, 18(2), 331–354. <https://doi.org/10.1021/acs.biomac.6b01455>

Ummartyotin, S., & Manuspiya, H. (2015). A critical review on cellulose: From fundamental to an approach on sensor technology. In *Renewable and Sustainable Energy Reviews* (Vol. 41, pp. 402–412). Elsevier Ltd. <https://doi.org/10.1016/j.rser.2014.08.050>

Urade, R., Sato, N., & Sugiyama, M. (2018). Gliadins from wheat grain: an overview, from primary structure to nanostructures of aggregates. In *Biophysical Reviews* (Vol. 10, Issue 2, pp. 435–443). Springer Verlag. <https://doi.org/10.1007/s12551-017-0367-2>

Uyar, T., Hacaloglu, J., & Besenbacher, F. (2009). Electrospun polystyrene fibers containing high temperature stable volatile fragrance/flavor facilitated by cyclodextrin inclusion complexes. *Reactive and Functional Polymers*, 69(3), 145–150. <https://doi.org/10.1016/j.reactfunctpolym.2008.12.012>

Uyar, T., Havelund, R., Nur, Y., Balan, A., Hacaloglu, J., Toppare, L., Besenbacher, F., & Kingshott, P. (2010). Cyclodextrin functionalized poly(methyl methacrylate) (PMMA) electrospun nanofibers for organic vapors waste treatment. *Journal of Membrane Science*, 365(1–2), 409–417. <https://doi.org/10.1016/j.memsci.2010.09.037>

Uyar, T., Kingshott, P., & Besenbacher, F. (2008). Electrospinning of cyclodextrin-pseudopolyrotaxane nanofibers. *Angewandte Chemie - International Edition*, 47(47), 9108–9111. <https://doi.org/10.1002/anie.200803352>

Uyar, T., Nur, Y., Hacaloglu, J., & Besenbacher, F. (2009). Electrospinning of functional poly(methyl methacrylate) nanofibers containing cyclodextrin-menthol inclusion complexes. *Nanotechnology*, 20(12). <https://doi.org/10.1088/0957-4484/20/12/125703>

Valencia, G. A., Zare, E. N., Makvandi, P., & Gutiérrez, T. J. (2019). Self-Assembled Carbohydrate Polymers for Food Applications: A Review. *Comprehensive Reviews in Food Science and Food Safety*, 18(6), 2009–2024. <https://doi.org/10.1111/1541-4337.12499>

Vass, P., Démuth, B., Farkas, A., Hirsch, E., Szabó, E., Nagy, B., Andersen, S. K., Vigh, T., Verreck, G., Csontos, I., Marosi, G., & Nagy, Z. K. (2019). Continuous alternative to freeze drying: Manufacturing

of cyclodextrin-based reconstitution powder from aqueous solution using scaled-up electrospinning. *Journal of Controlled Release*, 298(February), 120–127. <https://doi.org/10.1016/j.jconrel.2019.02.019>

Vass, P., Nagy, Z. K., Kóczyán, R., Fehér, C., Démuth, B., Szabó, E., Andersen, S. K., Vigh, T., Verreck, G., Csontos, I., Marosi, G., & Hirsch, E. (2020). Continuous drying of a protein-type drug using scaled-up fiber formation with HP- $\beta$ -CD matrix resulting in a directly compressible powder for tableting. *European Journal of Pharmaceutical Sciences*, 141(June 2019), 105089. <https://doi.org/10.1016/j.ejps.2019.105089>

Vega-Lugo, A. C., & Lim, L. T. (2009). Controlled release of allyl isothiocyanate using soy protein and poly(lactic acid) electrospun fibers. *Food Research International*, 42(8), 933–940. <https://doi.org/10.1016/j.foodres.2009.05.005>

Vicini, S., Mauri, M., Vita, S., & Castellano, M. (2018). Alginate and alginate/hyaluronic acid membranes generated by electrospinning in wet conditions: Relationship between solution viscosity and spinnability. *Journal of Applied Polymer Science*, 135(25), 46390. <https://doi.org/10.1002/app.46390>

Vigh, T., Horváthová, T., Balogh, A., Sóti, P. L., Drávavölgyi, G., Nagy, Z. K., & Marosi, G. (2013). Polymer-free and polyvinylpyrrolidone-based electrospun solid dosage forms for drug dissolution enhancement. *European Journal of Pharmaceutical Sciences*, 49(4), 595–602. <https://doi.org/10.1016/j.ejps.2013.04.034>

Wang, C., Wang, Y., & Hashimoto, T. (2016). Impact of Entanglement Density on Solution Electrospinning: A Phenomenological Model for Fiber Diameter. *Macromolecules*, 49(20), 7985–7996. <https://doi.org/10.1021/acs.macromol.6b00519>

Wang, J., Xu, H., Huo, Y., Wang, Y., & Dong, M. (2020). Progress of electrospray and electrospinning in energy applications. *Nanotechnology*, 31(13), 132001. <https://doi.org/10.1088/1361-6528/AB52BB>

Wang, Shan, Bai, J., Li, C., & Zhang, J. (2012). Functionalization of electrospun  $\beta$ -cyclodextrin/polyacrylonitrile (PAN) with silver nanoparticles: Broad-spectrum antibacterial property. *Applied Surface Science*, 261, 499–503. <https://doi.org/10.1016/j.apsusc.2012.08.044>

Wang, Shan, Bai, J., Li, C., Zhang, Y., & Zhang, J. (2012). Ag nanoparticle-embedded one-dimensional  $\beta$ -CD/PVP composite nanofibers prepared via electrospinning for use in antibacterial material. *Colloid and Polymer Science*, 290(7), 667–672. <https://doi.org/10.1007/s00396-011-2581-y>

1773 Wang, Sheng, Peng, J., Ma, J., & Xu, J. (2016). Protein Secondary Structure Prediction Using Deep  
 1774 Convolutional Neural Fields. *Scientific Reports*, 6(1), 1–11. <https://doi.org/10.1038/srep18962>

1775 Wang, Z., Zou, W., Liu, L., Wang, M., Li, F., & Shen, W. (2021). Characterization and bacteriostatic effects  
 1776 of  $\beta$ -cyclodextrin/quercetin inclusion compound nanofilms prepared by electrospinning. *Food*  
 1777 *Chemistry*, 338, 127980. <https://doi.org/10.1016/j.foodchem.2020.127980>

1778 Wankar, J., Kotla, N. G., Gera, S., Rasala, S., Pandit, A., & Rochev, Y. A. (2020). Recent Advances in Host–  
 1779 Guest Self- Assembled Cyclodextrin Carriers: Implications for Responsive Drug Delivery and  
 1780 Biomedical Engineering. *Advanced Functional Materials*, 30(44), 1909049.  
 1781 <https://doi.org/10.1002/adfm.201909049>

1782 Weisel, J. W., & Litvinov, R. I. (2017). Fibrin formation, structure and properties. *Sub-Cellular Biochemistry*,  
 1783 82, 405–456. [https://doi.org/10.1007/978-3-319-49674-0\\_13](https://doi.org/10.1007/978-3-319-49674-0_13)

1784 Wen, P., Zhu, D. H., Feng, K., Liu, F. J., Lou, W. Y., Li, N., Zong, M. H., & Wu, H. (2016). Fabrication of  
 1785 electrospun polylactic acid nanofilm incorporating cinnamon essential oil/ $\beta$ -cyclodextrin inclusion  
 1786 complex for antimicrobial packaging. *Food Chemistry*, 196, 996–1004.  
 1787 <https://doi.org/10.1016/j.foodchem.2015.10.043>

1788 Wen, P., Zhu, D. H., Wu, H., Zong, M. H., Jing, Y. R., & Han, S. Y. (2016). Encapsulation of cinnamon  
 1789 essential oil in electrospun nanofibrous film for active food packaging. *Food Control*, 59, 366–376.  
 1790 <https://doi.org/10.1016/j.foodcont.2015.06.005>

1791 Wen, P., Zong, M. H., Linhardt, R. J., Feng, K., & Wu, H. (2017). Electrospinning: A novel nano-  
 1792 encapsulation approach for bioactive compounds. *Trends in Food Science and Technology*, 70(July),  
 1793 56–68. <https://doi.org/10.1016/j.tifs.2017.10.009>

1794 Wu, H., Kong, J., Yao, X., Zhao, C., Dong, Y., & Lu, X. (2015). Polydopamine-assisted attachment of  $\beta$ -  
 1795 cyclodextrin on porous electrospun fibers for water purification under highly basic condition. *Chemical*  
 1796 *Engineering Journal*, 270, 101–109. <https://doi.org/10.1016/j.cej.2015.02.019>

1797 Xue, C., & Wilson, L. D. (2019). A spectroscopic study of solid-phase chitosan/cyclodextrin-based  
 1798 electrospun fibers. *Fibers*, 7(5). <https://doi.org/10.3390/FIB7050048>

1799 Xue, J., Wu, T., Dai, Y., & Xia, Y. (2019). Electrospinning and electrospun nanofibers: Methods, materials,  
 1800 and applications. *Chemical Reviews*, 119(8), 5298–5415. <https://doi.org/10.1021/acs.chemrev.8b00593>



1801 Xue, J., Xie, J., Liu, W., & Xia, Y. (2017). Electrospun Nanofibers: New Concepts, Materials, and  
 1802 Applications. *Accounts of Chemical Research*, 50(8), 1976–1987.  
 1803 <https://doi.org/10.1021/acs.accounts.7b00218>

1804 Yang, J., & Li, J. (2018). Self-assembled cellulose materials for biomedicine: A review. In *Carbohydrate*  
 1805 *Polymers* (Vol. 181, pp. 264–274). Elsevier Ltd. <https://doi.org/10.1016/j.carbpol.2017.10.067>

1806 Yi, Y., Xu, W., Wang, H. X., Huang, F., & Wang, L. M. (2020). Natural polysaccharides experience  
 1807 physiochemical and functional changes during preparation: A review. *Carbohydrate Polymers*, 234,  
 1808 115896. <https://doi.org/10.1016/j.carbpol.2020.115896>

1809 Yildiz, Zehra I., Celebioglu, A., Kilic, M. E., Durgun, E., & Uyar, T. (2018). Fast-dissolving  
 1810 carvacrol/cyclodextrin inclusion complex electrospun fibers with enhanced thermal stability, water  
 1811 solubility, and antioxidant activity. *Journal of Materials Science*, 53(23), 15837–15849.  
 1812 <https://doi.org/10.1007/s10853-018-2750-1>

1813 Yildiz, Zehra I., Kilic, M. E., Durgun, E., & Uyar, T. (2019). Molecular Encapsulation of Cinnamaldehyde  
 1814 within Cyclodextrin Inclusion Complex Electrospun Nanofibers: Fast-Dissolution, Enhanced Water  
 1815 Solubility, High Temperature Stability, and Antibacterial Activity of Cinnamaldehyde. *Journal of*  
 1816 *Agricultural and Food Chemistry*, 67(40), 11066–11076. <https://doi.org/10.1021/acs.jafc.9b02789>

1817 Yildiz, Zehra Irem, Celebioglu, A., Kilic, M. E., Durgun, E., & Uyar, T. (2018). Menthol/cyclodextrin  
 1818 inclusion complex nanofibers: Enhanced water-solubility and high-temperature stability of menthol.  
 1819 *Journal of Food Engineering*, 224, 27–36. <https://doi.org/10.1016/j.jfoodeng.2017.12.020>

1820 Yildiz, Zehra Irem, Celebioglu, A., & Uyar, T. (2017). Polymer-free electrospun nanofibers from sulfobutyl  
 1821 ether- $\beta$ -cyclodextrin (SBE7- $\beta$ -CD) inclusion complex with sulfisoxazole: Fast-dissolving and  
 1822 enhanced water-solubility of sulfisoxazole. *International Journal of Pharmaceutics*, 531(2), 550–558.  
 1823 <https://doi.org/10.1016/j.ijpharm.2017.04.047>

1824 Yildiz, Zehra Irem, & Uyar, T. (2019). Fast-dissolving electrospun nanofibrous films of  
 1825 paracetamol/cyclodextrin inclusion complexes. *Applied Surface Science*, 492(June), 626–633.  
 1826 <https://doi.org/10.1016/j.apsusc.2019.06.220>

1827 Yu, M., Dong, R.-H., Yan, X., Yu, G.-F., You, M.-H., Ning, X., & Long, Y.-Z. (2017). Recent Advances in  
 1828 Needleless Electrospinning of Ultrathin Fibers: From Academia to Industrial Production.

1829 *Macromolecular Materials and Engineering*, 302(7), 1700002.  
 1830 <https://doi.org/10.1002/mame.201700002>

1831 Yu, Y., Shen, M., Song, Q., & Xie, J. (2018). Biological activities and pharmaceutical applications of  
 1832 polysaccharide from natural resources: A review. In *Carbohydrate Polymers* (Vol. 183, pp. 91–101).  
 1833 Elsevier Ltd. <https://doi.org/10.1016/j.carbpol.2017.12.009>

1834 Yuan, G., Prabakaran, M., Qilong, S., Lee, J. S., Chung, I. M., Gopiraman, M., Song, K. H., & Kim, I. S.  
 1835 (2017). Cyclodextrin functionalized cellulose nanofiber composites for the faster adsorption of toluene  
 1836 from aqueous solution. *Journal of the Taiwan Institute of Chemical Engineers*, 70, 352–358.  
 1837 <https://doi.org/10.1016/j.jtice.2016.10.028>

1838 Yun, S. I., Lee, H. J., & Kim, B. H. (2020). Structure and electrochemical properties of highly conductive  
 1839 and porous carbon nanofiber derived from inclusion complex of cyclodextrin-phenylsilane. *Journal of*  
 1840 *Electroanalytical Chemistry*, 858, 113815. <https://doi.org/10.1016/j.jelechem.2019.113815>

1841 Zhang, C., Li, Y., Wang, P., & Zhang, H. (2020). Electrospinning of nanofibers: Potentials and perspectives  
 1842 for active food packaging. In *Comprehensive Reviews in Food Science and Food Safety* (Vol. 19, Issue  
 1843 2, pp. 479–502). Blackwell Publishing Inc. <https://doi.org/10.1111/1541-4337.12536>

1844 Zhang, W., Chai, H., & Diao, G. (2019). Highly porous cyclodextrin functionalized nanofibrous membrane  
 1845 by acid etching. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 582(June),  
 1846 123907. <https://doi.org/10.1016/j.colsurfa.2019.123907>

1847 Zhang, W., Chen, M., Zha, B., & Diao, G. (2012). Correlation of polymer-like solution behaviors with  
 1848 electrospun fiber formation of hydroxypropyl- $\beta$ -cyclodextrin and the adsorption study on the fiber.  
 1849 *Physical Chemistry Chemical Physics*, 14(27), 9729–9737. <https://doi.org/10.1039/c2cp41092c>

1850 Zhang, Ying- Ming, Liu, Y., & Liu, Y. (2020). Cyclodextrin- Based Multistimuli- Responsive  
 1851 Supramolecular Assemblies and Their Biological Functions. *Advanced Materials*, 32(3), 1806158.  
 1852 <https://doi.org/10.1002/adma.201806158>

1853 Zhang, Yong, Cui, L., Li, F., Shi, N., Li, C., Yu, X., Chen, Y., & Kong, W. (2016). Design, fabrication and  
 1854 biomedical applications of zein-based nano/micro-carrier systems. In *International Journal of*  
 1855 *Pharmaceutics* (Vol. 513, Issues 1–2, pp. 191–210). Elsevier B.V.  
 1856 <https://doi.org/10.1016/j.ijpharm.2016.09.023>

1857 Zhong, J., Mohan, S. D., Bell, A., Terry, A., Mitchell, G. R., & Davis, F. J. (2018). Electrospinning of food-  
1858 grade nanofibres from whey protein. *International Journal of Biological Macromolecules*, 113, 764–  
1859 773. <https://doi.org/10.1016/j.ijbiomac.2018.02.113>  
1860 Zhou, C., Abdel-Samie, M. A., Li, C., Cui, H., & Lin, L. (2020). Active packaging based on swim bladder  
1861 gelatin/galangal root oil nanofibers: Preparation, properties and antibacterial application. *Food*  
1862 *Packaging and Shelf Life*, 26, 100586. <https://doi.org/10.1016/j.fpsl.2020.100586>  
1863