



Download Print E-mail Save to PDF Add to List More... >

Locate full-text (opens in a new window) [Full Text](#)

*Polymers and Polymer Composites* • Open Access • Volume 29, Issue 9\_suppl, Pages S1023 - S1032 • November 2021

**Document type**

Article • Bronze Open Access

**Source type**

Journal

**ISSN**

09673911

**DOI**

10.1177/096739112111035068

View more

# Chemical and biological characterization of sulfated chitosan oligomer as heparin mimics

Kocabay, Samet<sup>a, b</sup>; Bahar, Mehmet Refik<sup>c</sup>; Tekin, Suat<sup>d</sup>; Akkaya, Recep<sup>e</sup>; Akkaya, Birnur<sup>a</sup>

Save all to author list

<sup>a</sup> Science Faculty, Department of Molecular Biology and Genetics, Cumhuriyet University, Sivas, Turkey

<sup>b</sup> Science and Literature Faculty, Department of Molecular Biology and Genetics, Inonu University, Malatya, Turkey

<sup>c</sup> Department of Nutrition and Dietetics, Osmaniye Ata Korkut University, Osmaniye, Turkey

<sup>d</sup> Faculty of Medicine, Department of Physiology, Inonu University, Malatya, Turkey

View additional affiliations

View PDF Full text options Export

**Abstract**

Author keywords

Indexed keywords

SciVal Topics

Metrics

Funding details

**Abstract**

In the present study, chitosan oligomer was modified to sulfated chitosan oligomer (ShCsO) to mimic heparin. Its chemical structure was determined by infrared spectroscopy (FT-IR), X-ray diffractometry (XRD), differential scanning calorimetry (DSC), and thermogravimetric analysis. The results showed that the FT-IR spectrum band at  $799\text{cm}^{-1}$  corresponds to C–O–S and that at  $1212\text{cm}^{-1}$  corresponds to S=O bond stretching, which prove that the sulfate groups are incorporated into chitosan oligomer successfully. The antimicrobial activity of ShCsO against to *Bacillus subtilis* in 1% concentration was  $89.1 \pm 1.7\%$ . The IC<sub>50</sub> ( $\mu\text{g/ml}$ ) of ShCsO was 67.75, 56.07, 85.47, and 84.68 for A2780, MCF-7, DU-145, and HepG2, respectively. The results show that this newly synthesized material is a potential candidate to heparin-like chitosan derivatives. According to the literature, it was the first time that chitosan oligomer was modified to mimic heparin. © The Author(s) 2021.

Author keywords

antimicrobial; chitosan oligomer; cytotoxicity; heparin; metastasis

Cited by 0 documents

Inform me when this document is cited in Scopus:

[Set citation alert >](#)

**Related documents**

Preparation of sulfatide mimicking oleic acid sulfated chitosan as a potential inhibitor for metastasis

Kocabay, S. , Akkaya, B. (2020) *International Journal of Biological Macromolecules*

Synthesis optimization, DFT and physicochemical study of chitosan sulfates

Kazachenko, A.S. , Akman, F. , Malyar, Y.N. (2021) *Journal of Molecular Structure*

Preparation of chitosan sulfate and vesicle formation with a conventional cationic surfactant

Zhang, B. , Yang, X. , Li, P. (2018) *Carbohydrate Polymers*






View all related documents based on references








Find more related documents in Scopus based on:

Authors > Keywords >

## References (62)






[View in search results format >](#) All[Export](#)  [Print](#)  [E-mail](#)  [Save to PDF](#) [Create bibliography](#)







- 
- 1 Bray, F., Ferlay, J., Soerjomataram, I., Siegel, R.L., Torre, L.A., Jemal, A.  
Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries ([Open Access](#))
- (2018) *CA Cancer Journal for Clinicians*, 68 (6), pp. 394-424. Cited 41790 times.  
[http://onlinelibrary.wiley.com/journal/10.3322/\(ISSN\)1542-4863](http://onlinelibrary.wiley.com/journal/10.3322/(ISSN)1542-4863)  
doi: 10.3322/caac.21492
-  [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 2 Zahedipour, F., Dalirfardouei, R., Karimi, G., Jamialahmadi, K.  
Molecular mechanisms of anticancer effects of Glucosamine
- (2017) *Biomedicine and Pharmacotherapy*, 95, pp. 1051-1058. Cited 28 times.  
[www.elsevier.com/locate/biomedpharm](http://www.elsevier.com/locate/biomedpharm)  
doi: 10.1016/j.biopha.2017.08.122
-  [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 3 Bendas, G., Borsig, L.  
Cancer cell adhesion and metastasis: Selectins, integrins, and the inhibitory potential of heparins ([Open Access](#))
- (2012) *International Journal of Cell Biology*, art. no. 676731. Cited 304 times.  
doi: 10.1155/2012/676731
-  [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 4 Linhardt, R.J.  
2003 Claude S. Hudson award address in carbohydrate chemistry. Heparin: Structure and activity
- (2003) *Journal of Medicinal Chemistry*, 46 (13), pp. 2551-2564. Cited 419 times.  
doi: 10.1021/jm030176m
-  [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 5 Rabenstein, D.L.  
Heparin and heparan sulfate: Structure and function
- (2002) *Natural Product Reports*, 19 (3), pp. 312-331. Cited 678 times.  
doi: 10.1039/b100916h
-  [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
-







- 6 Mohamed, S., Coombe, D.R.  
Heparin mimetics: Their therapeutic potential ([Open Access](#))  
  
(2017) *Pharmaceuticals*, 10 (4), art. no. 78. Cited 48 times.  
<http://www.mdpi.com/1424-8247/10/4/78/pdf>  
doi: 10.3390/ph10040078  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 7 Kansas, G.S.  
Selectins and their ligands: Current concepts and controversies ([Open Access](#))  
  
(1996) *Blood*, 88 (9), pp. 3259-3287. Cited 1231 times.  
<https://ashpublications.org/blood>  
doi: 10.1182/blood.v88.9.3259.bloodjournal8893259  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 8 Pomin, V.H.  
Sulfated glycans in inflammation  
  
(2015) *European Journal of Medicinal Chemistry*, 92, pp. 353-369. Cited 75 times.  
<http://www.journals.elsevier.com/european-journal-of-medicinal-chemistry/>  
doi: 10.1016/j.ejmech.2015.01.002  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 9 Ravi Kumar, M.N.V.  
A review of chitin and chitosan applications  
  
(2000) *Reactive and Functional Polymers*, 46 (1), pp. 1-27. Cited 3871 times.  
doi: 10.1016/S1381-5148(00)00038-9  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 10 Ogawa, K., Yui, T., Okuyama, K.  
Three D structures of chitosan  
  
(2004) *International Journal of Biological Macromolecules*, 34 (1-2), pp. 1-8. Cited 184 times.  
doi: 10.1016/j.ijbiomac.2003.11.002  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 11 Bernkop-Schnürch, A., Dünnhaupt, S.  
Chitosan-based drug delivery systems  
  
(2012) *European Journal of Pharmaceutics and Biopharmaceutics*, 81 (3), pp. 463-469. Cited 627 times.  
doi: 10.1016/j.ejpb.2012.04.007  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 12 Dash, M., Chiellini, F., Ottenbrite, R.M., Chiellini, E.  
Chitosan - A versatile semi-synthetic polymer in biomedical applications  
  
(2011) *Progress in Polymer Science (Oxford)*, 36 (8), pp. 981-1014. Cited 1907 times.  
<http://www.sciencedirect.com/science/journal/00796700>  
doi: 10.1016/j.progpolymsci.2011.02.001  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)

- 13 Dutta, P.K., Tripathi, S., Mehrotra, G.K., Dutta, J.  
**Perspectives for chitosan based antimicrobial films in food applications**  
(2009) *Food Chemistry*, 114 (4), pp. 1173-1182. Cited 1027 times.  
doi: 10.1016/j.foodchem.2008.11.047  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 14 Aider, M.  
**Chitosan application for active bio-based films production and potential in the food industry: Review**  
(2010) *LWT - Food Science and Technology*, 43 (6), pp. 837-842. Cited 577 times.  
doi: 10.1016/j.lwt.2010.01.021  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 15 Gerente, C., Lee, V.K.C., Le Cloirec, P., McKay, G.  
**Application of chitosan for the removal of metals from wastewaters by adsorption - Mechanisms and models review**  
(2007) *Critical Reviews in Environmental Science and Technology*, 37 (1), pp. 41-127. Cited 620 times.  
doi: 10.1080/10643380600729089  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 16 Liaqat, F., Eltem, R.  
**Chitooligosaccharides and their biological activities: A comprehensive review**  
(2018) *Carbohydrate Polymers*, 184, pp. 243-259. Cited 181 times.  
[http://www.elsevier.com/wps/find/journaldescription.cws\\_home/405871/description#description](http://www.elsevier.com/wps/find/journaldescription.cws_home/405871/description#description)  
doi: 10.1016/j.carbpol.2017.12.067  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 17 Wang, J., Zhang, J., Song, F., Gui, T., Xiang, J.  
**Purification and characterization of chitinases from ridgetail white prawn *Exopalaemon carinicauda* (Open Access)**  
(2015) *Molecules*, 20 (2), pp. 1955-1967. Cited 21 times.  
<http://www.mdpi.com/1420-3049/20/2/1955/pdf>  
doi: 10.3390/molecules20021955  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 18 Aam, B.B., Heggset, E.B., Norberg, A.L., Sørli, M., Vårum, K.M., Eijsink, V.G.H.  
**Production of chitooligosaccharides and their potential applications in medicine (Open Access)**  
(2010) *Marine Drugs*, 8 (5), pp. 1482-1517. Cited 408 times.  
<http://www.mdpi.com/1660-3397/8/5/1482/pdf>  
doi: 10.3390/md8051482  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 19 Kim, S.-K., Rajapakse, N.  
**Enzymatic production and biological activities of chitosan oligosaccharides (COS): A review**  
(2005) *Carbohydrate Polymers*, 62 (4), pp. 357-368. Cited 630 times.  
doi: 10.1016/j.carbpol.2005.08.012  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)






- 20 Harish Prashanth, K.V., Tharanathan, R.N.  
Chitin/chitosan: modifications and their unlimited application potential-an overview  
(2007) *Trends in Food Science and Technology*, 18 (3), pp. 117-131. Cited 815 times.  
doi: 10.1016/j.tifs.2006.10.022  
 Locate full-text(opens in a new window) View at Publisher
- 
- 21 Sobotta, L., Skupin-Mrugalska, P., Piskorz, J., Mielcarek, J.  
Porphyrinoid photosensitizers mediated photodynamic inactivation against bacteria  
(2019) *European Journal of Medicinal Chemistry*, 175, pp. 72-106. Cited 74 times.  
<http://www.journals.elsevier.com/european-journal-of-medicinal-chemistry/>  
doi: 10.1016/j.ejmech.2019.04.057  
 Locate full-text(opens in a new window) View at Publisher
- 
- 22 Hu, F.-Q., Zhao, M.-D., Yuan, H., You, J., Du, Y.-Z., Zeng, S.  
A novel chitosan oligosaccharide-stearic acid micelles for gene delivery: Properties and in vitro transfection studies  
(2006) *International Journal of Pharmaceutics*, 315 (1-2), pp. 158-166. Cited 191 times.  
[www.elsevier.com/locate/ijpharm](http://www.elsevier.com/locate/ijpharm)  
doi: 10.1016/j.ijpharm.2006.02.026  
 Locate full-text(opens in a new window) View at Publisher
- 
- 23 Karadeniz, F., Karagozlu, M.Z., Pyun, S.-Y., Kim, S.-K.  
Sulfation of chitosan oligomers enhances their anti-adipogenic effect in 3T3-L1 adipocytes  
(2011) *Carbohydrate Polymers*, 86 (2), pp. 666-671. Cited 25 times.  
doi: 10.1016/j.carbpol.2011.05.005  
 Locate full-text(opens in a new window) View at Publisher
- 
- 24 Kim, J.-H., Kim, Y.-S., Hwang, J.-W., Han, Y.-K., Lee, J.-S., Kim, S.-K., Jeon, Y.-J., (...), Park, P.-J.  
Sulfated chitosan oligosaccharides suppress LPS-induced NO production via JNK and NF-κB inactivation ([Open Access](#))  
(2014) *Molecules*, 19 (11), pp. 18232-18247. Cited 34 times.  
<http://www.mdpi.com/1420-3049/19/11/18232/pdf>  
doi: 10.3390/molecules191118232  
 Locate full-text(opens in a new window) View at Publisher
- 
- 25 Li, Y., Yu, F., Liu, Y., Liang, Q., Huang, Y., Xiang, Q., Zhang, Q., (...), Zhao, Y.  
Sulfonated chitosan oligosaccharide alleviates the inhibitory effect of basic fibroblast growth factor on osteogenic differentiation of human periodontal ligament stem cells  
(2020) *Journal of Periodontology*, 91 (7), pp. 975-985. Cited 5 times.  
<https://onlinelibrary.wiley.com/doi/10.1002/JPER.19-0273>  
doi: 10.1002/JPER.19-0273  
 Locate full-text(opens in a new window) View at Publisher

- 26 Lei, J., Yuan, Y., Lyu, Z., Wang, M., Liu, Q., Wang, H., Yuan, L., (...), Chen, H.  
Deciphering the Role of Sulfonated Unit in Heparin-Mimicking Polymer to Promote Neural Differentiation of Embryonic Stem Cells  
(2017) *ACS Applied Materials and Interfaces*, 9 (34), pp. 28209-28221. Cited 26 times.  
<http://pubs.acs.org/journal/aamick>  
doi: 10.1021/acsami.7b08034  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 27 Nahain, A.A., Ignjatovic, V., Monagle, P., Tsanaktsidis, J., Ferro, V.  
Heparin mimetics with anticoagulant activity ([Open Access](#))  
(2018) *Medicinal Research Reviews*, 38 (5), pp. 1582-1613. Cited 25 times.  
[http://onlinelibrary.wiley.com/journal/10.1002/\(ISSN\)1098-1128](http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1098-1128)  
doi: 10.1002/med.21489  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 28 Naggi, A., Torri, G., Compagnoni, T.  
Synthesis and physico-chemical properties of the polyampholyte chitosan 6-sulfate  
(1986) *Chitin in Nature and Technology*, pp. 371-377. Cited 19 times.  
Boston, MA, Springer, In
- 
- 29 Hirano, S., Tanaka, Y., Hasegawa, M., Tobetto, K., Nishioka, A.  
Effect of sulfated derivatives of chitosan on some blood coagulant factors  
(1985) *Carbohydrate Research*, 137 (C), pp. 205-215. Cited 96 times.  
doi: 10.1016/0008-6215(85)85161-2  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 30 Jayakumar, R., Nwe, N., Tokura, S., Tamura, H.  
Sulfated chitin and chitosan as novel biomaterials  
(2007) *International Journal of Biological Macromolecules*, 40 (3), pp. 175-181. Cited 525 times.  
doi: 10.1016/j.ijbiomac.2006.06.021  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 31 Muzzarelli, R.A., Jeuniaux, C., Gooday, G.W.  
(1986) *Chitin in Nature and Technology*. Cited 632 times.  
Boston, MA, Springer
- 
- 32 Park, P.-J., Je, J.-Y., Jung, W.-K., Ahn, C.-B., Kim, S.-K.  
Anticoagulant activity of heterochitosans and their oligosaccharide sulfates  
(2004) *European Food Research and Technology*, 219 (5), pp. 529-533. Cited 59 times.  
doi: 10.1007/s00217-004-0977-3  
 Locate full-text(opens in a new window) [View at Publisher](#)
-

- 33 Wang, J., Wang, H.  
Preparation of soluble p-aminobenzoyl chitosan ester by Schiff's base and antibacterial activity of the derivatives  
(2011) *International Journal of Biological Macromolecules*, 48 (3), pp. 523-529. Cited 53 times.  
doi: 10.1016/j.ijbiomac.2011.01.016  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 34 Cai, J., Dang, Q., Liu, C., Wang, T., Fan, B., Yan, J., Xu, Y.  
Preparation, characterization and antibacterial activity of O-acetyl-chitosan-N-2-hydroxypropyl trimethyl ammonium chloride  
(2015) *International Journal of Biological Macromolecules*, 80, pp. 8-15. Cited 44 times.  
[www.elsevier.com/locate/ijbiomac](http://www.elsevier.com/locate/ijbiomac)  
doi: 10.1016/j.ijbiomac.2015.05.061  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 35 Jou, C.-H.  
Antibacterial activity and cytocompatibility of chitosan-N-hydroxy-2,3-propyl-N methyl-N,N-diallylammonium methyl sulfate  
(2011) *Colloids and Surfaces B: Biointerfaces*, 88 (1), pp. 448-454. Cited 17 times.  
doi: 10.1016/j.colsurfb.2011.07.028  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 36 Denizot, F., Lang, R.  
Rapid colorimetric assay for cell growth and survival. Modifications to the tetrazolium dye procedure giving improved sensitivity and reliability  
(1986) *Journal of Immunological Methods*, 89 (2), pp. 271-277. Cited 4167 times.  
doi: 10.1016/0022-1759(86)90368-6  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 37 Mourya, V.K., Inamdar, N.N., Choudhari, Y.M.  
Chitooligosaccharides: Synthesis, characterization and applications  
(2011) *Polymer Science - Series A*, 53 (7), pp. 583-612. Cited 155 times.  
doi: 10.1134/S0965545X11070066  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 38 Cardoso, J., Nava, D., García-Morán, P., Hernández-Sánchez, F., Gomez, B., Vazquez-Arenas, J., González, I.  
Synthesis, characterization, and theoretical insights of green chitosan derivatives presenting enhanced Li<sup>+</sup> ionic conductivity  
(2015) *Journal of Physical Chemistry C*, 119 (9), pp. 4655-4665. Cited 20 times.  
<http://pubs.acs.org/journal/jpcck>  
doi: 10.1021/jp5128699  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)

- 39 Wang, T., Zhou, Y., Xie, W., Chen, L., Zheng, H., Fan, L.  
**Preparation and anticoagulant activity of N-succinyl chitosan sulfates**  
(2012) *International Journal of Biological Macromolecules*, 51 (5), pp. 808-814. Cited 30 times.  
doi: 10.1016/j.ijbiomac.2012.07.029  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 40 Nishimura, S.-I., Kai, H., Shinada, K., Yoshida, T., Tokura, S., Kurita, K., Nakashima, H., (...), Uryu, T.  
**Regioselective syntheses of sulfated polysaccharides: Specific anti- HIV-1 activity of novel chitin sulfates**  
(1998) *Carbohydrate Research*, 306 (3), pp. 427-433. Cited 189 times.  
doi: 10.1016/S0008-6215(97)10081-7  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 41 Vongchan, P., Sajomsang, W., Subyen, D., Kongtawelert, P.  
**Anticoagulant activity of a sulfated chitosan**  
(2002) *Carbohydrate Research*, 337 (13), pp. 1239-1242. Cited 138 times.  
[www.elsevier.com/locate/carres](http://www.elsevier.com/locate/carres)  
doi: 10.1016/S0008-6215(02)00098-8  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 42 Le Tien, C., Lacroix, M., Ispas-Szabo, P., Mateescu, M.-A.  
**N-acylated chitosan: Hydrophobic matrices for controlled drug release**  
(2003) *Journal of Controlled Release*, 93 (1), pp. 1-13. Cited 266 times.  
[www.elsevier.com/locate/jconrel](http://www.elsevier.com/locate/jconrel)  
doi: 10.1016/S0168-3659(03)00327-4  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 43 Li, Y., Zhang, S., Meng, X., Chen, X., Ren, G.  
**The preparation and characterization of a novel amphiphilic oleoyl-carboxymethyl chitosan self-assembled nanoparticles**  
(2011) *Carbohydrate Polymers*, 83 (1), pp. 130-136. Cited 44 times.  
doi: 10.1016/j.carbpol.2010.07.030  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 44 Katugampola, P., Winstead, C.  
**Rheological behavior and thermal stability of palmitoyl chitosan varying the degree of substitution**  
(2014) *Int J Pharm Sci Invent*, 3, pp. 24-32. Cited 7 times.
- 
- 45 Moraes, A.F., Moreira Filho, R.N.F., Passos, C.C.O., Cunha, A.P., Silva, L.M.A.E., Freitas, L.B.N., Vasconcelos, N.F., (...), Vieira, R.S.  
**Hemocompatibility of 2-N-3,6-O-sulfated chitosan films**  
(2019) *Journal of Applied Polymer Science*, 136 (9), art. no. 47128. Cited 10 times.  
[http://onlinelibrary.wiley.com/journal/10.1002/\(ISSN\)1097-4628](http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1097-4628)  
doi: 10.1002/app.47128  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)



- 46 Lokwani, R., Singh, R., Kukreti, G.  
Extraction and quantification of sulfated glycosaminoglycan content in five aquatic species of Malaysia  
(2015) *J Coast Life Med*, 3, pp. 677-681.
- 
- 47 Reena, S., Sunil Kumar, S., Muthusamy, T., Velmurugan, K.  
Anticoagulant Potential Of Marine Polychaete (Nereis Species)  
(2013) *Journal of Biological & Scientific Opinion Volume*, 1 (4).
- 
- 48 Yang, T., Hussain, A., Bai, S., Khalil, I.A., Harashima, H., Ahsan, F.  
Positively charged polyethylenimines enhance nasal absorption of the negatively charged drug, low molecular weight heparin ([Open Access](#))  
  
(2006) *Journal of Controlled Release*, 115 (3), pp. 289-297. Cited 85 times.  
doi: 10.1016/j.jconrel.2006.08.015  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 49 Karthik, R., Manigandan, V., Saravanan, R., Rajesh, R.P., Chandrika, B.  
Structural characterization and in vitro biomedical activities of sulfated chitosan from *Sepia pharaonis*  
  
(2016) *International Journal of Biological Macromolecules*, 84, pp. 319-328. Cited 32 times.  
[www.elsevier.com/locate/ijbiomac](http://www.elsevier.com/locate/ijbiomac)  
doi: 10.1016/j.ijbiomac.2015.12.030  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 50 Zhang, X., Sun, J.  
Synthesis, Characterization, and Properties of Sulfonated Chitosan for Protein Adsorption ([Open Access](#))  
  
(2020) *International Journal of Polymer Science*, 2020, art. no. 9876408. Cited 3 times.  
<http://www.hindawi.com/journals/ijps/>  
doi: 10.1155/2020/9876408  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 51 Sabar, S., Abdul Aziz, H., Yusof, N.H., Subramaniam, S., Foo, K.Y., Wilson, L.D., Lee, H.K.  
Preparation of sulfonated chitosan for enhanced adsorption of methylene blue from aqueous solution  
  
(2020) *Reactive and Functional Polymers*, 151, art. no. 104584. Cited 30 times.  
<https://www.journals.elsevier.com/reactive-and-functional-polymers>  
doi: 10.1016/j.reactfunctpolym.2020.104584  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
- 
- 52 Tsai, H.-S., Wang, Y.-Z., Lin, J.-J., Lien, W.-F.  
Preparation and properties of sulfopropyl chitosan derivatives with various sulfonation degree  
  
(2010) *Journal of Applied Polymer Science*, 116 (3), pp. 1686-1693. Cited 48 times.  
<http://www3.interscience.wiley.com/cgi-bin/fulltext/123227645/PDFSTART>  
doi: 10.1002/app.31689  
 [Locate full-text\(opens in a new window\)](#) [View at Publisher](#)
-

- 53 Dimassi, S., Tabary, N., Chai, F., Blanchemain, N., Martel, B.  
**Sulfonated and sulfated chitosan derivatives for biomedical applications: A review**  
  
(2018) *Carbohydrate Polymers*, 202, pp. 382-396. Cited 78 times.  
[http://www.elsevier.com/wps/find/journaldescription.cws\\_home/405871/description#description](http://www.elsevier.com/wps/find/journaldescription.cws_home/405871/description#description)  
doi: 10.1016/j.carbpol.2018.09.011  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 54 No, H.K., Young Park, N., Ho Lee, S., Meyers, S.P.  
**Antibacterial activity of chitosans and chitosan oligomers with different molecular weights**  
  
(2002) *International Journal of Food Microbiology*, 74 (1-2), pp. 65-72. Cited 1125 times.  
doi: 10.1016/S0168-1605(01)00717-6  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 55 Pires, N.R., Cunha, P.L.R., Maclel, J.S., Angelim, A.L., Melo, V.M.M., De Paula, R.C.M., Feitosa, J.P.A.  
**Sulfated chitosan as tear substitute with no antimicrobial activity (Open Access)**  
  
(2013) *Carbohydrate Polymers*, 91 (1), pp. 92-99. Cited 48 times.  
doi: 10.1016/j.carbpol.2012.08.011  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 56 Chokradjaroen, C., Theeramunkong, S., Yui, H., Saito, N., Rujiravanit, R.  
**Cytotoxicity against cancer cells of chitosan oligosaccharides prepared from chitosan powder degraded by electrical discharge plasma**  
  
(2018) *Carbohydrate Polymers*, 201, pp. 20-30. Cited 30 times.  
[http://www.elsevier.com/wps/find/journaldescription.cws\\_home/405871/description#description](http://www.elsevier.com/wps/find/journaldescription.cws_home/405871/description#description)  
doi: 10.1016/j.carbpol.2018.08.037  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 57 Huang, R., Mendis, E., Rajapakse, N., Kim, S.-K.  
**Strong electronic charge as an important factor for anticancer activity of chito oligosaccharides (COS)**  
  
(2006) *Life Sciences*, 78 (20), pp. 2399-2408. Cited 137 times.  
doi: 10.1016/j.lfs.2005.09.039  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 58 Jiang, M., Ouyang, H., Ruan, P., Zhao, H., Pi, Z., Huang, S., Yi, P., (...), Crepin, M.  
**Chitosan derivatives inhibit cell proliferation and induce apoptosis in breast cancer cells**  
  
(2011) *Anticancer Research*, 31 (4), pp. 1321-1328. Cited 30 times.  
 Locate full-text(opens in a new window) [View at Publisher](#)
- 
- 59 Zhang, A., Wang, X., Deng Shu, E.  
**Inhibition of sulfonated chitosan on human breast cancer cell line MCF-7**  
(2010) *Prog Mod Biomed*, 10, pp. 1842-1844.

- 60 Saiki, I., Murata, J., Azuma, I., Nakajima, M., Tokura, S.  
Inhibition by Sulfated Chitin Derivatives of Invasion through Extracellular Matrix and Enzymatic Degradation by Metastatic Melanoma Cells

(1990) *Cancer Research*, 50 (12), pp. 3631-3637. Cited 135 times.


 [Locate full-text](#)(opens in a new window)

- 61 Wang, R., Huang, J., Wei, M., Zeng, X.  
The synergy of 6-O-sulfation and N-or 3-O-sulfation of chitosan is required for efficient inhibition of P-selectin-mediated human melanoma A375 cell adhesion

(2010) *Bioscience, Biotechnology and Biochemistry*, 74 (8), pp. 1697-1700. Cited 14 times.

[http://www.jstage.jst.go.jp/article/bbb/74/8/1697/\\_pdf](http://www.jstage.jst.go.jp/article/bbb/74/8/1697/_pdf)

doi: 10.1271/bbb.100140


 [Locate full-text](#)(opens in a new window) [View at Publisher](#)


- 62 Sandhya, M., Aparna, V., Maneesha K., S., Raja, B., Jayakumar, R., Sathianarayanan, S.  
Amphotericin B loaded sulfonated chitosan nanoparticles for targeting macrophages to treat intracellular *Candida glabrata* infections

(2018) *International Journal of Biological Macromolecules*, 110, pp. 133-139. Cited 29 times.

[www.elsevier.com/locate/ijbiomac](http://www.elsevier.com/locate/ijbiomac)

doi: 10.1016/j.ijbiomac.2018.01.028

 [Locate full-text](#)(opens in a new window) [View at Publisher](#)

 Akkaya, B.; Science Faculty, Department of Molecular Biology and Genetics, Cumhuriyet University, Sivas, Turkey; email:bakkaya@cumhuriyet.edu.tr

© Copyright 2021 Elsevier B.V., All rights reserved.

## About Scopus

[What is Scopus](#)

[Content coverage](#)

[Scopus blog](#)

[Scopus API](#)

[Privacy matters](#)

## Language

[日本語に切り替える](#)

[切换到简体中文](#)

[切换到繁體中文](#)

[Русский язык](#)

## Customer Service

[Help](#)

[Tutorials](#)

[Contact us](#)

---

## ELSEVIER

[Terms and conditions](#) ↗ [Privacy policy](#) ↗

Copyright © Elsevier B.V. ↗. All rights reserved. Scopus® is a registered trademark of Elsevier B.V.

We use cookies to help provide and enhance our service and tailor content. By continuing, you agree to the use of cookies.

