

硫酸多糖生物活性研究进展

阿地拉·艾皮热, 李金玉, 付长霜, 周方方, 李金耀*

(新疆生物资源基因工程重点实验室/新疆大学 生命科学与技术学院, 新疆 乌鲁木齐 830046)

摘要: 硫酸多糖也被称为多糖的硫酸化衍生物,是硫酸根取代了多糖结构中单糖分子的部分羟基而形成的一类具有多种功能的物质,可以通过天然提取或硫酸化的结构修饰而得到。近年的研究证明硫酸多糖具有显著的抗肿瘤、抗病毒、抗氧化、抗凝血等活性,对机体免疫系统有一定调控作用。作者对硫酸多糖生物学功能的近期研究进行了总结,并对后续研究进行了展望。

关键词: 硫酸多糖;抗病毒;抗氧化;抗肿瘤;抗凝血;免疫调节

中图分类号: R 285.5 **文献标志码:** A **DOI:** 10.3969/j.issn. 1673-1689.2019.01.002

Research Progress on Bioactivity of Sulfate Polysaccharide

ADILA Aipire, LI Jinyu, FU Changshuang, ZHOU Fangfang, LI Jinyao*

(Xinjiang Key Laboratory of Biological Resources and Genetic Engineering / College of Life Science and Technology, Xinjiang University, Urumqi 830046, China)

Abstract: Sulfated polysaccharides can be extracted from natural resources or modified from polysaccharides through substitution of the hydroxyl groups of monosaccharide molecules on polysaccharide chains by sulfate. The sulfated polysaccharides have multiple functions, such as anti-tumor, anti-virus, anti-oxidation, anti-coagulation and immunoregulation. In this paper, the recent studies on the biological functions of sulfated polysaccharides were summarized, and the future research was proposed.

Keywords: Sulfate polysaccharide, anti-virus, anti-oxidation, anti-tumor, anti-coagulation, immunoregulation

糖的生物学活性已为人们所共识。经过对糖生物学的多年不懈研究,人们已总结出一套应用于多糖的分离提取和结构解析高效的分析技术;同时对其抗氧化、抗感染、促进免疫等多方面功能和生物活性的研究也取得了较大进展^[1-4]。多糖的生物活性

与其物理化学性质密切相关,如分子大小、单糖类型和比率以及糖苷结构特性等^[5]。近年来多糖的化学分子修饰尤其是硫酸化修饰极大引起了研究者的兴趣。硫酸多糖是一类富含带有负电荷硫酸根的化合物^[6],包括从动、植物中提取的各种天然硫酸多

收稿日期: 2016-09-09

基金项目: 新疆维吾尔自治区自然科学基金项目(2015211C258)。

作者简介: 阿地拉·艾皮热(1989—),女,维吾尔族,博士研究生,主要从事分子免疫学研究。E-mail: 1291288638@qq.com

* 通信作者: 李金耀(1981—),男,博士,教授,主要从事分子免疫学研究。E-mail: ljyxju@xju.edu.cn

引用本文: 阿地拉·艾皮热,李金玉,付长霜,等. 硫酸多糖生物活性研究进展[J]. 食品与生物技术学报,2019,38(01):07-13.

糖(如肝素),天然中性多糖的硫酸硫酸化修饰物及人工合成,半合成的各种硫酸多糖。硫酸多糖因具有广泛的生物学性质而受到人们的关注^[7-8]。

1 硫酸多糖来源

1.1 天然硫酸多糖

硫酸多糖也称多糖硫酸酯或硫酸酯多糖,最先发现于软骨素以及从猪肠粘膜中提取的肝素,后来发现它还广泛存在于海藻类植物。肝素是动物体内一种天然抗凝血物质,临床上有广泛应用^[9-10]。

海藻中红藻、褐藻、绿藻等含有丰富的硫酸多糖。红藻细胞壁上提取的卡拉胶^[11]、海洋褐藻和棘皮动物中提取的糖硫酸酯、绿藻提取物硫酸化半乳糖^[12]具有多种生物活性如抗病毒、抗肿瘤、抗凝血等而无毒副作用,可用于食品、药物及保健品中^[13]。

1.2 硫酸化修饰多糖

目前制备硫酸化多糖常用方法包括浓硫酸法、氯磺酸-吡啶法、三氧化硫-吡啶法、氯磺酸-甲酰胺法等^[7,14]。硫酸基团的引入对多糖多种生物活性有影响。糖分子自由-OH 被-SO₃H 取代后,使多糖的电荷和静电作用会增加,从而增强水溶性和构象的转变。Zhang 等^[15]通过氯磺酸-吡啶法修饰灵芝多糖,检测其物理化学性质、生物学功能的变化,发现其水溶性随取代度的增加而增加,并且提高了其抗氧化和抗肿瘤活性。多糖经硫酸化后具有多方面的生

物活性或者是增强了原来多糖的生物活性,这与它的硫酸根取代度、相对分子质量、结构转变有关^[16]。

2 硫酸多糖生物活性

2.1 抗病毒

1958 年, Gerber^[17]首次报道硫酸多糖的抗病毒活性,他们研究发现从石花菜中提取的硫酸多糖 cartilagenium 能预防鸡胚被流感病毒 B 和腮腺炎病毒感染。许多种类的海藻含有大量的结构复杂的硫酸多糖已被证明抑制包膜病毒的复制,包括 DNA、RNA 病毒等(见表 1)。川明参多糖是一种天然的硫酸多糖,在 77.12~104.81 μg/mL 质量浓度范围内显著抑制鸭肠炎病毒 (Duck enteritis virus, DEV) 的活性^[18]。

木耳 (*Auricularia auricula*) 在亚洲具有悠久的历史应用历史,被广泛用于医药和保健品中。木耳重要活性成分多糖(AAP)具有生物学功能。Nguyen 等人^[28]研究发现木耳多糖硫酸化修饰后比修饰前相比抗病毒活性增强。硫酸多糖主要是作用于病毒囊膜蛋白,从而阻止病毒感染早期阶段,包括初始吸附到靶细胞以及病毒的侵入^[29]。

2.2 抗氧化

活性氧 (ROS) 攻击细胞膜大分子蛋白质和 DNA,导致严重的组织损伤性疾病,如癌症、糖尿病、神经退行性疾病和炎症。抗氧化剂可以减缓活

表 1 从不同的海藻中提取的硫酸多糖的抗病毒活性

Table 1 Antiviral activity of sulfated polysaccharides from different seaweeds

来源	主要成分	病毒类型	IC ₅₀ /(μg/mL)	参考文献
红藻类				
<i>Cryptonemia seminervis</i>	DL-galactan	HMPV	12.5~100	[19]
<i>Scinaia hatei</i>	xylomannans	DENV	1.1	[20]
<i>Gracilaria corticata</i>	galactan	DENV	10.0	[20]
<i>Lithothamnion muelleri</i>	heterosaccharide	HSV-1, HSV-2		[21]
<i>Nemalion helminthoides</i>	Mannose	HSV-1	5.4	[22]
褐藻类				
<i>Sargassum patens</i>	D-galactose	HSV-1	1.5	[23]
<i>Sphacelaria indica</i>	Xylogalactofucan, Sea oxalic acid	HSV-1		[24]
<i>Adenocystis utricularis</i>	Fucoidan	HIV-1	0.6~70	[25]
<i>Laminaria angustata</i>	xylogalactofucan	HSV-1	0.2~25	[26]
绿藻类				
<i>Caulerpa racemosa</i>	heterosaccharide	DENV	0.6	[20]
<i>Codium fragile</i>	Galactose	HSV-2	4.7	[27]

性氧,如 $\text{OH}\cdot$ 、 H_2O_2 和 O^{2-} 引起的氧化应激过程,有益于人体健康^[30]。许多合成的抗氧化剂在食品和医药行业中被广泛应用,如二叔丁基对甲酚、叔丁基羟基茴香醚(BHA)、特丁基对苯二酚(TBHQ)和没食子酸丙酯(PG)等。然而,这些合成的抗氧化剂具有一定的毒副作用^[31-32]。天然抗氧化剂具有不可替代的优势,如硫酸多糖等。已有文献报道,江蓠(*Gracilaria debilis*)^[33]、毛茛(*Pterocladia capillacea*)^[34]、裂片石莼(*Ulva fasciata*)^[35]以及肠浒苔(*Ulva intestinalis*)热水提取物中的褐藻素、海带多糖、海藻酸等成分具有很强的清除 DPPH、 $\text{O}_2^{\cdot-}$ 、 $\text{OH}\cdot$ 、 H_2O_2 的活性,是良好的抗氧化剂。Yuan 等^[36]采用微波提取技术从球型褐藻中提取其硫酸多糖,发现在不同温度水浴条件下提取的岩藻糖(fucose)和葡萄糖醛酸(glucuronic acid)都具有清除 DPPH 和还原能力。

党参多糖(CP)是党参(*Codonopsis pilosula*)重要的活性成分,具有药理活性。Liu 等人^[37]采用氯磺酸一吡啶法对其进行酯化改性,提高了其清除自由基活性。体内实验结果显示,硫酸化党参多糖(sCP)能显著降低肝损伤模型小鼠血液中谷丙转氨酶(ALT)、谷草转氨酶(AST)、肿瘤坏死因子- α (TNF- α)和肝组织丙二醛(MDA)的含量,并且肝组织中 SOD、GSH-Px 显著高于模型组和党参多糖组。结果表明,天然多糖经过硫酸化修饰后其抗氧化活性会发生不同程度的增强。

2.3 抗肿瘤

目前恶性肿瘤已被认为是危害人类健康的疾病之一。天然硫酸多糖已被证明具有较强的抗肿瘤活性,其抗肿瘤活性主要表现在抑制肿瘤细胞的增殖,促进肿瘤细胞凋亡以及通过提高免疫系统的功能来协同杀伤肿瘤细胞。马尾藻(*Sargassum horneri*)水溶性硫酸多糖 SHP30 能将人结肠癌上皮细胞(DLD)阻止在 G0/G1 期,从而抑制其生长;实时荧光 PCR 结果显示,它降低了 Bcl-2 的表达,增加了 Bax 的表达^[38]。已有的研究发现硫酸化修饰可在一定程度上提高多糖抗肿瘤活性。O-硫酸化大肠杆菌 K5 荚膜多糖(OS-K5PS)能抑制纤维母细胞生长因子(fibroblast growth factor, FGF)的表达而抑制乳腺癌细胞 S115 的增殖,而 NS,OS-K5PS 没有这种活性^[39]。然而,Teng 等报道了 NS,OS-K5PS 显著抑制 SDF-1/CXCL12 趋化因子诱导的 B16 黑色素瘤细胞的增殖,使细胞周期停滞在 G0/G1 期,而且其抑制

效果高于 OS-K5PS^[40]。另一研究发现,NS,OS-K5PS 能抑制转化生长因子- β 1(transforming growth factor- β , TGF- β)诱导的骨转移性乳腺癌细胞 MDA-MB-231 中溶骨因子 IL-11 的表达,小鼠模型证明 NS,OS-K5PS 抑制了肿瘤的生长和癌细胞的转移^[41]。硫酸多糖不同的生物活性可能与硫酸取代度、硫酸化作用的位点密切相关。

2.4 抗凝血

肝素是最早应用于临床的天然抗凝剂,它具有相对分子质量小、抗血栓作用强、口服易吸收、体内半衰期长、生物利用度高等优点,有望成为安全、高效的抗血栓类药物^[42-43]。海藻类富含硫酸多糖,也是天然抗凝剂的丰富来源^[44]。松藻(*Codium divaricatum*)^[45]及礁膜(*Monostroma oxyspermum*)^[46]硫酸多糖能剂量依赖性地延长凝血酶活化时间。因此,天然硫酸多糖在预防及治疗由凝血造成的心血管疾病(包括心肌梗塞、中风、深静脉血栓形成等)方面具有巨大的应用潜力。

2.5 免疫调节

研究表明,硫酸多糖具有免疫调节作用,包括免疫促进作用和免疫抑制作用。Cao 等人^[47]从昆布(*Ecklonia cava*)水提取物中通过阴离子交换色谱分离纯化得到其硫酸多糖,并检测其免疫增强作用。Western blot 结果显示,昆布硫酸多糖通过 MAPK 和 NF- κ B 信号通路促进 RAW264.7 细胞产生一氧化氮(nitric oxide, NO)和促炎因子。从酿酒酵母(*saccharomyces cerevisiae*)得到的硫酸葡聚糖单独免疫小鸡后增强了小鸡脾脏中免疫细胞的分化,与新城疫疫苗同时免疫小鸡后 42 d,能显著提高血液中抗体滴度和细胞因子白介素-2(interleukin-2, IL-2)和 γ -干扰素(interferon- γ , IFN- γ)的表达水平^[48]。然而,紫菜(*Porphyra haitanensis*)多糖能抑制过敏性小鼠血清中 IgG、IgG1 以及 IgE 水平,降低脾脏细胞中 Th2 型细胞因子(IL-4、IL-5 和 IL-13)的表达,增强了 Th1 型细胞因子 IFN- γ 的表达^[49]。

研究发现,适当的分子修饰或结构改变使多糖产生新的活性或进一步增强原有的功能,尤其是硫酸化修饰。硫酸修饰会显著提高多糖的免疫调节作用,如增强免疫细胞的增殖,促进细胞因子的产生,作为佐剂增强疫苗免疫反应或抑制促炎因子的产生而抑制炎症的发生等(见表 2)。

表 2 硫酸化修饰多糖的免疫调节活性

Table 2 Immune regulate activity of sulfated polysaccharides

生物学活性	来源	硫酸化修饰方法	参考文献
抗炎作用	<i>Antrodia cinnamomea</i>	维素硫酸酯化	[50]
	<i>Armillariella mellea</i>	维维素硫酸酯化	[51]
	<i>Astragalus polysaccharide</i>	氯磺酸-吡啶法	[52-53]
	<i>Radix Astragali</i>	氯磺酸-吡啶法	[54]
免疫增强作用	<i>Ganoderma atrum</i>	氯磺酸-吡啶法	[55]
	<i>Ganoderma lucidum</i>	硫磺三氧三甲胺	[56]
	<i>Bush Sophora</i>	氯磺酸-吡啶法	[57]
	<i>Poria cocos</i>	氯磺酸-吡啶法	[58]
疫苗佐剂作用	<i>Astragalus polysaccharide</i>	氯磺酸-吡啶法	[59]
	<i>Auricularia auricula</i>	氯磺酸-吡啶法	[60]
	<i>Tremella, Codonopsis pilosula</i>	氯磺酸-吡啶法	[61]
	<i>Ophiopogon japonicus, Fructus jujubae</i>	氯磺酸-吡啶法	[62]

3 展望

天然来源的产物在医药、营养食品、药用化妆品和功能性食物等领域研究取得了多方面的进展,如动、植物、微生物来源的多糖,尤其是硫酸多糖,具有多种生物活性^[63]。最近的研究表明,天然多糖经人工硫酸化修饰后不仅可以增强其原有的生物活性,还可产生新的生物活性。硫酸多糖在医药、营养食品、药用化妆品和功能性食物等领域具有广阔的应用前景(图1)。目前使用的多糖硫酸化修饰方法包括氯磺酸-吡啶法、三氧化硫-吡啶法、浓硫酸法

等,使用的都是强酸、强氧化、强腐蚀性溶剂,如果反应时间过长,易引起多糖降解,导致原有活性丢失。需要对反应体系进一步优化(如加入催化剂),提高反应速率,降低多糖降解率。多糖硫酸化修饰后的活性与其水溶性、相对分子质量、硫酸基团取代度、硫酸基团的位置及多糖结构变化等具有相关性。因此,需要对多糖硫酸化的工艺进行优化,包括反应时间、硫酸化试剂、溶剂与多糖溶解度、调节剂等,明确不同工艺修饰后硫酸多糖的结构变化,检测硫酸多糖结构与功效之间的关系,建立质量控制标准;同时需要加强硫酸多糖的毒副作用相关研究,为其临床应用奠定基础。

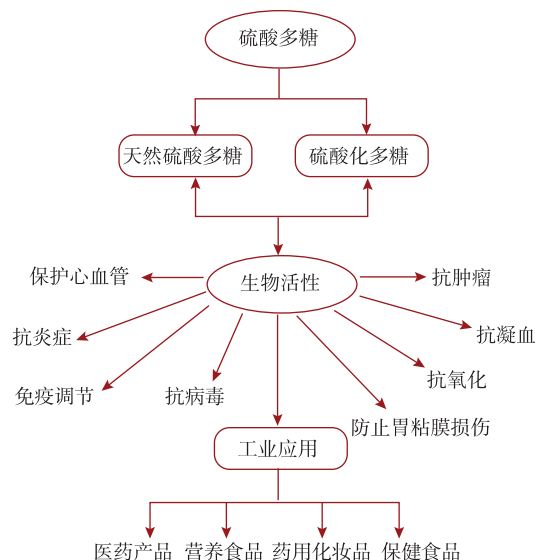


图 1 硫酸多糖的生物学特性和潜在的工业用途

Fig. 1 Biological properties and potential industrial uses of Sulfate polysaccharide

参考文献:

- [1] EMAM H E, AHMED H B. Polysaccharides templates for assembly of nanosilver[J]. *Carbohydr Polym*, 2016, 135: 300-307.
- [2] XIE J H, LIU X, SHEN M Y, et al. Purification, physicochemical characterisation and anticancer activity of a polysaccharide from *Cyclocarya paliurus* leaves[J]. *Food Chem*, 2013, 136(3): 1453-1460.
- [3] LI X Y, WANG L, WANG Z Y et al. Primary characterization and protective effect of polysaccharides from *Hohenbuehelia serotina* against γ -radiation induced damages in vitro[J]. *Ind Crop Prod*, 2014, 61: 265-271.
- [4] ZONG A, CAO H, WANG F. Anticancer polysaccharides from natural resources: A review of recent research [J]. *Carbohydr Polym*, 2012, 90(4): 1395-1410.
- [5] LIN C C, PAN I H, LI Y R, et al. The adjuvant effects of high-molecule-weight polysaccharides purified from *antrodia cinnamomea* on dendritic cell function and DNA vaccines[J]. *Plos One*, 2015, 10(2).
- [6] NIU T T, ZHANG D S, CHEN H M, et al. Modulation of the binding of basic fibroblast growth factor and heparanase activity by purified λ -carrageenan oligosaccharides[J]. *Carbohydr Polym*, 2015, 125: 76-84.

- [7] LI Yanhua, TAN Chengyu, WANG Xiuwu, et al. Progresses on preparation of sulfated polysaccharides and its bioactivity[J]. **Fine and Specialty Chemicals**, 2006, 14(16): 6-9. (in Chinese)
- [8] NETO E M, SOMBRA V G, RICHTER A R, et al. Chemically sulfated galactomannan from *Dimorphandra gardneriana* seed: Characterization and toxicity evaluation[J]. **Carbohydr Polym**, 2014, 101: 1013-1017.
- [9] ARUNGUNDRAM S, AL-MAFRAJI K, ASONG J, et al. Modular synthesis of heparan sulfate oligosaccharides for structure? activity relationship studies[J]. **J AM CHEM SOC**, 2009, 131(47): 17394-17405.
- [10] GALEOTTI F, VOLPI N. Novel reverse-phase ion pair-high performance liquid chromatography separation of heparin, heparan sulfate and low molecular weight-heparins disaccharides and oligosaccharides[J]. **J Chromatogr A**, 2013, 1284: 141-147.
- [11] RUNNING C A, FALSHAW R, JANASWAMY S. Trivalent iron induced gelation in lambda-carrageenan[J]. **Carbohydr Polym**, 2012, 87(4): 2735-2739.
- [12] POMIN V H, MOURAO P A S. Structure, biology, evolution, and medical importance of sulfated fucans and galactans[J]. **Glycobiology**, 2008, 18(12): 1016-1027.
- [13] WIJESINGHE W, JEON Y J. Biological activities and potential industrial applications of fucose rich sulfated polysaccharides and fucoidans isolated from brown seaweeds: A review[J]. **Carbohydr Polym**, 2012, 88(1): 13-20.
- [14] XIE Mingyong, WANG Zhijun, XIE Jianhua. Research progress on the sulfated modification of polysaccharides and its structure-bioactivities relationship [J]. **Journal of Chinese Institute of Food Science and Technology**, 2015 (2): 1-8. (in Chinese)
- [15] ZHANG H, WANG J Q, NIE S P, et al. Sulfated modification, characterization and property of a water-insoluble polysaccharide from *Ganoderma atrum*[J]. **Int J Biol Macromol**, 2015, 79: 248-255.
- [16] WANG J, YANG W, YANG T, et al. Catalytic synthesis of sulfated polysaccharides I: Characterization of chemical structure[J]. **Int J Biol Macromol**, 2015, 74: 61-67.
- [17] SONG X, YIN Z, ZHAO X, et al. Antiviral activity of sulfated Chuanmingshen violaceum polysaccharide against Newcastle disease virus[J]. **J Gen Virol**, 2013, 94(Pt 10): 2164-2174.
- [18] SONG X, YIN Z, LI L, et al. Antiviral activity of sulfated Chuanminshen violaceum polysaccharide against duck enteritis virus in vitro[J]. **Antivir Res**, 2013, 98(2): 344-351.
- [19] MENDES G S, DUARTE M E R, COLODI F G, et al. Structure and anti-metapneumovirus activity of sulfated galactans from the red seaweed *Cryptonemia seminervis*[J]. **Carbohydr Polym**, 2014, 101: 313-323.
- [20] PUJOL C A, RAY S, RAY B, et al. Antiviral activity against dengue virus of diverse classes of algal sulfated polysaccharides[J]. **Int J Biol Macromol**, 2012, 51(4): 412-416.
- [21] MALAGOLI B G, CARDOZO F T G S, GOMES J H S, et al. Chemical characterization and antiherpes activity of sulfated polysaccharides from *Lithothamnion muelleri*[J]. **Int J Biol Macromol**, 2014, 66: 332-337.
- [22] RECALDE M P, NOSEDA M D, PUJOL C A, et al. Sulfated mannans from the red seaweed *Nemalion helminthoides* of the South Atlantic[J]. **Phytochemistry**, 2009, 70(8): 1062-1068.
- [23] ZHU W, CHIU L C M, OOI V E C, et al. Antiviral property and mechanisms of a sulphated polysaccharide from the brown alga *Sargassum patens* against Herpes simplex virus type 1[J]. **Phytomedicine**, 2006, 13(9): 695-701.
- [24] BANDYOPADHYAY S S, NAVID M H, GHOSH T, et al. Structural features and in vitro antiviral activities of sulfated polysaccharides from *Sphacelaria indica*[J]. **Phytochemistry**, 2011, 72(2): 276-283.
- [25] TRINCHERO J, PONCE N, CORDOBA O L, et al. Antiretroviral activity of fucoidans extracted from the brown seaweed *Adenocystis utricularis*[J]. **Phytother Res**, 2009, 23(5): 707-712.
- [26] SAHA S, NAVID M H, BANDYOPADHYAY S S, et al. Sulfated polysaccharides from *Laminaria angustata*: Structural features and in vitro antiviral activities[J]. **Carbohydr Polym**, 2012, 87(1): 123-130.
- [27] OHTA Y, LEE J B, HAYASHI K, et al. Isolation of sulfated galactan from *Codium fragile* and its antiviral effect [J]. **Biol Pharm Bull**, 2009, 32(5): 892-898.
- [28] NGUYEN T L, CHEN J, HU Y, et al. In vitro antiviral activity of sulfated *Auricularia auricula* polysaccharides [J]. **Carbohydr Polym**, 2012, 90(3): 1254-1258.
- [29] HARDEN E A, FALSHAW R, CARNACHAN S M, et al. Virucidal activity of polysaccharide extracts from four algal species

- against herpes simplex virus[J]. **Antivir Res**, 2009, 83(3):282-289.
- [30] YANG Y, LIU D, WU J, et al. In vitro antioxidant activities of sulfated polysaccharide fractions extracted from *Corallina officinalis*[J]. **Int J Biol Macromol**, 2011, 49(5):1031-1037.
- [31] WIJESEKARA I, PANGESTUTI R, KIM S K. Biological activities and potential health benefits of sulfated polysaccharides derived from marine algae[J]. **Carbohydr Polym**, 2011, 84(1):14-21.
- [32] ZHANG A, XIAO N, HE P, et al. Chemical analysis and antioxidant activity in vitro of polysaccharides extracted from *Boletus edulis*[J]. **Int J Biol Macromol**, 2011, 49(5):1092-1095.
- [33] SUDHARSAN S, SUBHAPRADHA N, SEEDEVI P, et al. Antioxidant and anticoagulant activity of sulfated polysaccharide from *Gracilaria debilis*(Forsskal)[J]. **Int J Biol Macromol**, 2015, 81:1031-1038.
- [34] FLEITA D, EI-SAYED M, RIFAAT D. Evaluation of the antioxidant activity of enzymatically-hydrolyzed sulfated polysaccharides extracted from red algae; *Pterocladia capillacea*[J]. **Lwt-Food Sci Technol**, 2015.
- [35] SHAO P, CHEN M, PEI Y, et al. In vitro antioxidant activities of different sulfated polysaccharides from chlorophyten seaweeds *Ulva fasciata*[J]. **Int J Biol Macromol**, 2013, 59:295-300.
- [36] YUAN Y, MACGUARRIE D. Microwave assisted extraction of sulfated polysaccharides (fucoidan) from *Ascophyllum nodosum* and its antioxidant activity[J]. **Carbohydr Polym**, 2015, 129:101-107.
- [37] LIU C, CHEN J, LI E, et al. The comparison of antioxidative and hepatoprotective activities of *Codonopsis pilosula* polysaccharide (CP) and sulfated CP[J]. **Int Immunopharmacol**, 2015, 24(2):299-305.
- [38] SHAO P, CHEN X, SUN P. Chemical characterization, antioxidant and antitumor activity of sulfated polysaccharide from *Sargassum horneri*[J]. **Carbohydr Polym**, 2014, 105:260-269.
- [39] BORGENSTROM M, JALKANEU M, SALMIVIRTA M. Sulfated derivatives of *Escherichia coli* K5 polysaccharides as modulators of fibroblast growth factor signaling[J]. **J Biol Chem**, 2003, 278(50):49882-49889.
- [40] TENG L, FU H, DENG C, et al. Modulating the SDF-1/CXCL12-induced cancer cell growth and adhesion by sulfated K5 polysaccharides in vitro[J]. **Biomed Pharmacother**, 2015.
- [41] POLLARI S, KAKONEN R S, MOHAMMAD K S, et al. Heparin-like polysaccharides reduce osteolytic bone destruction and tumor growth in a mouse model of breast cancer bone metastasis[J]. **Mol Cancer Res**, 2012, 10(5):597-604.
- [42] HUANG Xiaoyan, KONG Xiangfeng, WANG Deyun, et al. Research progression sulfating modification of polysaccharides and sulfated polysaccharides[J]. **Natural Product Research**, 2007, 19(2):328-332. (in Chinese)
- [43] MANSOUR M B, DHAHRI M, HASSINE M, et al. Highly sulfated dermatan sulfate from the skin of the ray *Raja montagui*: anticoagulant activity and mechanism of action [J]. **Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology**, 2010, 156(3):206-215.
- [44] SOUZA R O S, ASSREUY A M S, Madeira J C, et al. Purified polysaccharides of *Geoffroea spinosa* barks have anticoagulant and antithrombotic activities devoid of hemorrhagic risks[J]. **Carbohydr Polym**, 2015, 124:208-215.
- [45] LI N, MAO W, YAN M, et al. Structural characterization and anticoagulant activity of a sulfated polysaccharide from the green alga *Codium divaricatum*[J]. **Carbohydr Polym**, 2015, 121:175-182.
- [46] SEEDEVI P, MOOVENDHAN M, SUDHARSAN S, et al. Structural characterization and bioactivities of sulfated polysaccharide from *Monostroma oxyspermum*[J]. **Int J Biol Macromol**, 2015, 72:1459-1465.
- [47] CAO R A, LEE Y J, YOU S G. Water soluble sulfated-fucans with immune-enhancing properties from *Ecklonia cava* [J]. **Int J Biol Macromol**, 2014, 67:303-311.
- [48] WANG M, YANG R, ZHANG L, et al. Sulfated glucan can improve the immune efficacy of Newcastle disease vaccine in chicken [J]. **Int J Biol Macromol**, 2014, 70:193-198.
- [49] SHI C, PAN T, CAO M, et al. Suppression of Th2 immune responses by the sulfated polysaccharide from *Porphyra haitanensis* in tropomyosin-sensitized mice[J]. **Int Immunopharmacol**, 2015, 24(2):211-218.
- [50] CHENG J J, CHAO C H, CHANG P C, et al. Studies on anti-inflammatory activity of sulfated polysaccharides from cultivated fungi *Antrodia cinnamomea*[J]. **Food Hydrocolloid**, 2014.
- [51] CHANG C W, LUR H S, LU M K, et al. Sulfated polysaccharides of *Armillariella mellea* and their anti-inflammatory activities via NF- κ B suppression[J]. **Food Res Int**, 2013, 54(1):239-245.

- [52] WANG X, LI Y, SHEN J, et al. Effect of Astragalus polysaccharide and its sulfated derivative on growth performance and immune condition of lipopolysaccharide-treated broilers[J]. *Int J Biol Macromol*, 2015, 76: 188-194.
- [53] WANG X, WANG S, LI Y, et al. Sulfated Astragalus polysaccharide can regulate the inflammatory reaction induced by LPS in Caco2 cells[J]. *Int J Biol Macromol*, 2013, 60: 248-252.
- [54] WANG X, SHEN J, LI S, et al. Sulfated Astragalus polysaccharide regulates the inflammatory reaction in LPS-infected broiler chicks[J]. *Int J Biol Macromol*, 2014, 69: 146-150.
- [55] CHEN Y, ZHANG H, WANG Y, et al. Sulfated modification of the polysaccharides from *Ganoderma atrum* and their antioxidant and immunomodulating activities[J]. *Food Chem*, 2015, 186: 231-238.
- [56] XU Z, CHEN X, ZHONG Z, et al. *Ganoderma lucidum* polysaccharides: immunomodulation and potential anti-tumor activities[J]. *Am J Chinese Med*, 2011, 39(1): 15-27.
- [57] CHEN Y, WU Y, XIAN L, et al. Effects of Bush Sophora Root polysaccharide and its sulfate on immuno-enhancing of the therapeutic DVH[J]. *Int J Biol Macromol*, 2015, 80: 217-224.
- [58] WANG H, MUKERABIGWI J F, ZHANG Y, et al. In vivo immunological activity of carboxymethylated-sulfated (1 → 3) -β-D-glucan from sclerotium of *Poria cocos*[J]. *Int J Biol Macromol*, 2015.
- [59] HUANG X, HU Y, ZHAO X, et al. Sulfated modification can enhance the adjuvant activity of astragalus polysaccharide for ND vaccine[J]. *Carbohydr Polym*, 2008, 73(2): 303-308.
- [60] NGUYEN T L, WANG D, HU Y, et al. Immuno-enhancing activity of sulfated *Auricularia auricula* polysaccharides [J]. *Carbohydr Polym*, 2012, 89(4): 1117-1122.
- [61] ZHAO X, HU Y, WANG D, et al. The comparison of immune-enhancing activity of sulfated polysaccharides from *Tremella* and *Condonopsis pilosula*[J]. *Carbohydr Polym*, 2013, 98(1): 438-443.
- [62] ZHANG J, CHEN J, WANG D, et al. Immune-enhancing activity comparison of sulfated ophiopogon polysaccharide and sulfated jujube polysaccharide[J]. *Int J Biol Macromol*, 2013, 52: 212-217.
- [63] XIE Mingyong, NIE Shaoping. A review of the research progress on tea polysaccharide [J]. *Journal of Food Science and Biotechnology*, 2006, 25(2): 107-114. (in Chinese)

会 议 消 息

会议名称: 中国化学会第二届全国有机自由基化学会议

会议时间: 2019年4月12-14日

会议地点: 广东省深圳市

主办方: 中国化学会

承办方: 1、中国化学会有机化学学科委员会; 2、南方科技大学; 3、中科院上海有机化学研究所;

会议主题: 自由基与催化

大会主席: 李超忠

会议网站: <http://www.orgradical2.cn/>

联系人: 刘心元

电子邮箱: liuxy@sustc.edu.cn

电 话: 0755-8801-8314

地 址: 广东省深圳市南山区学苑大道1088号

会议内容: 展示近年来国内在有机自由基化学领域取得的研究成果, 促进有机自由基化学及相关学科的发展壮大。主要交流内容: 1、有机自由基反应; 2、有机光催化; 3、有机电化学; 4、不对称自由基反应; 5、自由基在合成中的应用; 6、自由基机理研究。