研究报告

2008—2023年中国猪肉生产链污染沙门菌的血清型和耐药特征分析

刘世伟[1,2],卢晓红[2],齐妍[2],盛焕精[2,3],崔生辉[4],白莉[2]

(1. 山东第二医科大学公共卫生学院,山东 潍坊 261053;2. 国家食品安全风险评估中心 国家卫生健康委员会食品安全风险评估重点实验室,北京 100021;3. 西北农林科技大学食品科学与工程学院,陕西 咸阳 712100;4. 中国食品药品检定研究院,北京 100050)

摘 要:目的 基于文献系统分析2008—2023年中国猪肉生产链污染沙门菌的血清型及耐药特征。**方法** 在中国知网、PubMed等数据库中检索2008—2023年间发表的中国猪肉生产链沙门菌相关文献,经筛选得83篇,并利用SPSS、Excel对数据进行统计分析,按时间跨度将文献分为3个时间段:T1(2008—2012年)、T2(2013—2017年)和T3(2018—2023年),且与欧盟和美国同源数据血清型及抗菌药物敏感性进行对比分析。**结果** 2008—2023年间中国猪肉生产链沙门菌污染的整体平均阳性率为18.0%,其中屠宰环节(19.6%)和零售环节(29.1%)的阳性率均高于养殖环节(8.4%),并远高于欧盟(屠宰:1.4%;零售:1.7%)和美国(屠宰:15.9%;零售:1.4%)($P<0.05$)。中国猪肉生产链沙门菌中最常见的血清型为德尔卑(28.4%)、鼠伤寒及单相变种(24.7%)和罗森沙门菌(12.9%),不同时间段的污染率存在消长:德尔卑逐渐下降,鼠伤寒及单相变种与罗森沙门菌逐渐增多。5种猪源沙门菌(德尔卑、鼠伤寒及单相变种、肠炎、伦敦和罗森沙门菌)对多西环素(85.1%)、四环素(78.8%)、氨苄西林(65.1%)和氯霉素(61.5%)等抗菌药物耐药率较高,且显著高于欧盟和美国($P<0.05$)。氨苄西林、复方新诺明、四环素、环丙沙星的耐药率随时间增长呈上升趋势,分别增长38.3%、28.2%、18.0%、15.1%。**结论** 中国猪肉生产链沙门菌的污染率较高,部分优势血清型存在消长,四环素类等抗菌药物的耐药率在整体上呈上升趋势。因此建议加强对猪肉生产链中兽用抗菌药物的使用监管。

关键词:中国;猪肉;沙门菌;污染;血清型;耐药特征

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Characterization of serovars and drug resistance of *Salmonella* contaminating pork production chains in China, 2008-2023

LIU Shiwei[1,2], LU Xiaohong[2], QI Yan[2], SHENG Huanjing[2,3], CUI Shenghui[4], BAI Li[2]

(1. School of Public Health, Shandong Second Medical University,Shandong Weifang 261053, China; 2. China National Center for Food Safety Risk Assessment, NHC Key Laboratory of Food Safety Risk Assessment, Beijing 100021, China; 3. School of Food Science and Engineering, Northwest Agriculture and Forestry University, Shaanxi Xianyang 712100, China; 4. China National Institute of Food and Drug Control , Beijing 100050, China)

Abstract: Objective To systematically analyze the serovars and drug resistance characteristics of *Salmonella* contaminated with pork production chain in China from 2008 to 2023 based on literature. **Methods** The literature related to *Salmonella* in the pork production chain in China published from 2008 to 2023 was searched in China Knowledge and PubMed databases and 83 articles were screened. The data were statistically analyzed by using SPSS and Excel. According to time span, the literature were divided into three time periods: T1 (2008-2012), T2 (2013—2017) and T3 (2018—2023) and were analyzed in comparison with the European Union and the United States homologous data on serovars and antimicrobial susceptibility. **Results** The average positivity rate of *Salmonella* contamination in pork production chains in China from 2008 to 2023 was 18.0%, with higher positivity rates in both the slaughter (19.6%) and retail (29.1%) segments than in the farmed segment (8.4%), which was much higher than that in the EU (slaughter: 1.4%; retail:

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作者简介:刘世伟 男 在读研究生 研究方向为食品微生物 E-mail:liusw798@163.com

通信作者:白莉 女 研究员 研究方向为食品微生物 E-mail:baili@cfsa.net.cn

1.7%) and the United States (slaughter: 15.9%; retail: 1.4%) (P<0.05). The most common serovars of *Salmonella* of pork origin in China were *Samonella* Derby (28.4%), *Samonella* Typhimurium and *Samonella* I 4,[5],12:i:- (24.7%) and *Samonella* Rissen (12.9%) and the rate of contamination varied over time: a gradual decrease in Derby, and a gradual increase in *Samonella* Typhimurium and *S.* I 4,[5],12:i:- and *Samonella* Rissen. Five *Salmonella* of swine origin (*Samonella* Derby, *Samonella* Typhimurium and *Samonella* I 4,[5],12:i:-, *Salmonella* Enteritidis, *Samonella* london and *Samonella* Rissen) had high rates of resistance to antimicrobial drugs such as doxycycline (85.1%), tetracycline (78.8%), ampicillin (65.1%) and chloramphenicol (61.5%) and were significantly higher than those in the EU and the USA (P<0.05). The resistance rates of ampicillin, cotrimoxazole, tetracycline and ciprofloxacin showed an increasing trend with time, increasing by 38.3%, 28.2%, 18.0% and 15.1%, respectively. **Conclusion** The contamination rate of *Salmonella* from pork sources in China was high, there was an elimination of some dominant serovars. The resistance rate of tetracycline antimicrobials showed an increasing trend in the whole. It is recommended to strengthen the regulation of the use of veterinary antimicrobial drugs in the pork production chain.

Key words: China; pork; *Salmonella*; contamination; serovars; resistance profile

沙门菌是全球范围内最常见的食源性致病菌之一,由其导致的沙门菌病病发率位居我国散发和暴发病例的第一位,其中生鲜猪肉是我国人群罹患沙门菌病的重要来源[1-2]。

我国是全球猪肉生产和消费大国,猪肉消费量占肉类消费总量的75.0%[3];此外,每年约有超过8 000吨的抗生素用于畜禽养殖[4-5]。因此,对猪肉中沙门菌的污染、血清型及耐药情况等开展监测和评估,有助于提升我国的食品质量安全。欧盟和美国通过对食品、患者及动物三方面进行食源性致病菌监测以来,已掌握包括沙门菌在内的多种食源性致病菌污染及耐药趋势,为相关政策制定提供了重要的科学支撑[6-7]。我国对猪肉中沙门菌的污染和耐药情况也进行了大量研究,但已有研究多针对生产链的某个阶段或某个省份进行分析,尚未对猪肉生产全链条中污染沙门菌的血清型和耐药情况等进行系统分析[2]。因此,本研究基于文献系统分析了2008—2023年中国19个省份猪肉生产链中污染沙门菌血清型与抗菌药物敏感性数据(详见附表:https://kdocs.cn/l/clYdZlqRvyO9),与欧盟和美国的同源数据进行对比分析,为我国猪肉源沙门菌的污染防控提供数据支撑。

1 材料与方法

1.1 文献检索策略

以“(主题:猪(精确))OR(主题:猪肉(精确))AND((主题:沙门菌(精确))OR(主题:沙门氏菌(精确)))AND((摘要:流行率)OR(摘要:检测)OR(摘要:耐药)OR(摘要:血清型)AND(全文:中国)”为中文关键词和以“((*Salmonella* AND (pork OR pig OR pigs) AND (prevalence OR prevalent OR detection OR serovar OR serovars OR serovar OR serovars) OR resistance OR resistant AND (China))”为英文关键词,在PubMed、Web of science、中国知网和万方数据库中进行检索,获得2008年1月—2023年12月公开发表的中英文研究结果。

1.2 纳入标准和剔除标准

纳入标准:①2008年1月-2023年12月国内外公开发表的原始文献;②涉及猪肉生产全链条或部分链条的文献(即包括养殖、屠宰和零售全阶段或部分阶段);③研究内容明确涉及沙门菌的采样总数量及阳性样本数量。剔除标准:①重复发表的文献;②综述或Meta分析类等文献;③采样时间、地点等基础性数据记录缺失或描述不清的文献。

1.3 研究选择与数据提取

通过阅读文章标题、摘要及全文,提取纳入文章中的第一作者、研究地点、研究时间、发表时间、样品来源、样品数量、阳性数量、菌株血清型、抗生素种类、耐药率等信息,并导入Excel表格中用于后续分析统计。

1.4 统计学分析

采用Excel 2016和SPSS 25.0软件进行数据整理和统计分析,计算数据以百分率(%)表示。利用SPSS进行χ^2检验和回归分析并计算P值,以P<0.05为差异有统计学意义,并判断不同时间和地区来源的数据汇总后的可靠性。同时计算95%的置信区间。

2 结果与讨论

本次调查中按关键词检索共获得1 941篇文献。通过时间筛选和去除重复文献后,初步得到1 602篇文献。经筛选后,得到160篇与猪肉生产链中沙门菌相关的文献。进一步排除数据缺失的文献、综述类及Meta分析类文献,最终获得83篇文献,具体的文献筛选流程见图1。83篇文献[8-90]涉及生产链的养殖环节(25篇)、屠宰环节(34篇)和零售环节(46篇),其中15篇包含多个环节;涉及

沙门菌血清分布、耐药特征分布的文献分别有58篇和13篇。为开展系统的对比分析，按时间跨度将83篇文献划分为3个时间段：T1（2008—2012年）、T2（2013—2017年）和T3（2018—2023年），文献的具体分布情况见表1[91]。

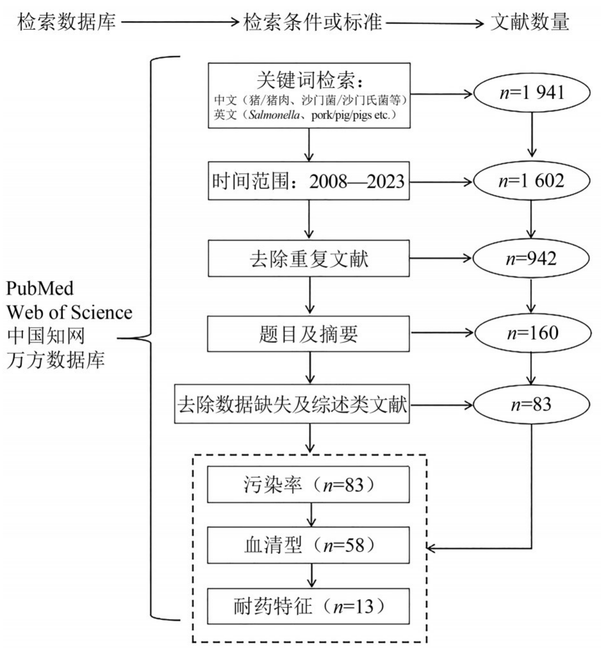

图1　文献筛选流程图

Figure 1　Literature screening flowchart

2.1　我国猪肉生产链中沙门菌污染情况分析

2008—2023年间中国在猪肉养殖、屠宰和零售环节的沙门菌污染情况见表2。鉴于数据涵盖了多个时间段和地区，可能存在一定的偏移（如不同时间段的文献数量不一致且个别［如省份（江苏）来源的文献数量明显多于其他省份］。为判断采样年份和地区是否对沙门菌感染率产生显著影响，本研究采用了回归分析的方法来验证数据稳健性，结果表明，采样年份（P=0.732）和地区（P=0.388）对沙门菌污染率均未产生显著影响（P>0.05）。结合采样年份和地区进行分析时，发现二者联合对结果也无显著性影响（P=0.374）[92]。但考虑到检测方法的多样性，且文献中的猪肉样本流通性较强，尚不能确定文献研究中涉及的猪肉样品为国内养殖产品还是进口分割产品。因此，本研究采用95%置信区间（Confidence interval，CI）来提高数据的准确性[93]。其中，来自养殖场、屠宰场和零售市场的猪肉样品中沙门菌的平均污染率分别为8.4%（95%CI：7.8~9.0）、19.6%（95%CI：18.8~20.4）和29.1%（95%CI：27.9~30.3）。来自屠宰和零售环节的猪肉样品中沙门菌的污染率显著高于来自养殖环节的猪肉样品中沙门菌的污染率（P<0.05），这可能与屠宰加工过程未严格遵守卫生规范、运输和储藏不当引发的交叉污染有关[94]。

通过对不同时间段沙门菌的污染情况进行分析发现，来自养殖环节的猪肉样品中沙门菌的阳性率由6.9%（T1）和4.0%（T2）上升到12.0%（T3）；来自零售环节的猪肉样品中沙门菌的阳性率由17.8%（T1）上升至43.8%（T2），到T3时间段下降为24.8%。来自屠宰环节的猪肉样品中沙门菌的阳性率则呈下降趋势，由24.0%（T1）下降至23.6%（T2）再下降至16.5%（T3），具体情况见表2。经过文献调研分析发现，这可能是由于2018年8月非洲猪瘟暴发，促使我国加强了屠宰场的卫生清洁消毒等措施，以及改善屠宰过程中的条件（包括采用更好的杀菌消毒措施及自动化清洗装置）[95]。这与中国动物卫生与流行病学中心监测的数据一致[96]。与国外数据对比发现，无论是在屠宰还是零售环节，我国猪肉沙门污染率（屠宰：19.6%；零售：29.1%）显著高于欧盟（屠宰：1.4%；零售：1.7%）和美国（屠宰：15.9%；零售：1.4%）（P<0.05）[6,97-100]，具体结果见表3。

2.2　我国猪肉生产链中沙门菌血清型分布情况

2008—2023年我国猪肉生产链中常见的沙门菌血清型为德尔卑（28.4%）、鼠伤寒及单相变种（24.7%）、罗森（12.9%）和伦敦沙门菌（8.7%）（表4），这一结果与2022年中国发表的一篇综述研究一致[2]。自1923年德尔卑沙门菌被发现以来，其已在全球范围内广泛传播，特别是在猪和猪肉产品中[103]。从表5可知，沙门菌的优势血清型在T1~T3 3个时间段内发生了明显的变化。其中，鼠伤寒沙门菌及单相变种的数量及占比明显增多，这与以往的研究结果一致，已成为我国腹泻患者中的重要沙门菌血清型[104-105]。此外，罗森沙门菌的数量及占比变化也显著增加，已成为我国猪肉生产链中排名第3的血清型。2015年欧洲食品安全局（European Food Safety Authority，EFSA）和欧洲疾病预防和控制中心（European Centre for Disease Prevention and Control，

表1　本研究纳入的83篇文献分布情况

Table 1　Distribution of the 83 articles included in this study

发表年份	文献数量	涉及环节	污染率（文献数量）	血清型（文献数量）	耐药性（文献数量）
2008—2012	15	养殖、屠宰、零售	15	13	5
2013—2017	30	养殖、屠宰、零售	30	27	7
2018—2023	38	养殖、屠宰、批发、零售	38	18	1
合计	83	养殖、屠宰、批发、零售	83	58	13

表2 2008—2023年沙门菌阳性率在我国猪肉不同生产链环节情况

Table 2 Prevalence of *Salmonella* from different stages of the pork production chain in China from 2008 to 2023 originating from included studies

采样阶段	采样年份	样本数	阳性数	阳性率/%	95%*CI*
养殖	2008—2012	4 719	325	6.9	6.2~7.7
	2013—2017	5 437	215	4.0	3.5~4.5
	2018—2023	8 660	1 039	12.0	11.3~12.7
	合计	18 816	1 579	8.4	8.0~8.9
屠宰	2008—2012	567	136	24.0	20.7~27.7
	2013—2017	7 699	1 817	23.6	22.7~24.6
	2018—2023	10 695	1 767	16.5	15.8~17.2
	合计	18 961	3 720	19.6	19.0~20.3
零售	2008—2012	2 646	470	17.8	16.3~19.3
	2013—2017	4 084	1 788	43.8	42.3~45.3
	2018—2023	6 959	1 723	24.8	23.8~25.8
	合计	13 689	3 981	29.1	28.3~30.0
全生产链	2008—2012	7 932	931	11.7	11.1~12.5
	2013—2017	17 220	3 820	22.2	21.6~22.8
	2018—2023	26 314	4 529	17.2	16.8~17.7
	合计	51 466	9 280	18.0	17.7~18.4

表3 沙门菌污染在中国、欧盟和美国猪源中的情况

Table 3 Epidemiology of *Salmonella* in pork slaughter and retail in the China, European Union and the United States

国家	年份	阶段	总样品数量	阳性数量	阳性率/%
中国	2008—2023	屠宰	18 961	3 720	19.6
		零售	13 689	3 981	29.1
欧盟	2018—2022	屠宰	524 092	7 470	1.4
		零售	95 539	1 616	1.7
美国	2018—2022	屠宰	30 900	4 901	15.9
	2002—2020	零售	28 762	415	1.4

ECDC)发表的报告中将罗森沙门菌列为与人类沙门菌病有关的20种最常见的血清型之一,其同样也是欧盟肉猪和家禽产品相关的十大血清型之一[106]。相反德尔卑沙门菌占比明显下降。上述3种血清型的变化情况与2023年发表的一篇关于我国猪肉沙门菌血清变化研究趋势一致[107]。自2018年非洲猪瘟暴发以来,我国生猪养殖场和屠宰场都大幅加强了卫生清洁消毒等措施[96],而鼠伤寒沙门菌对消毒剂的抗性较其他血清型更强[108],可能是其占比变化的原因。

与欧盟和美国猪肉沙门菌血清型比较发现,各国的优势血清型存在差异。根据欧盟2022年发布的数据显示,猪肉中沙门菌排名前3的优势血清型为鼠伤寒及单相变种(47.7%)、德尔卑(24.0%)和婴儿沙门菌(4.9%)[6];美国农业部2022年发布的数据显示,美国猪肉中沙门菌排名前3的优势血清型为婴儿沙门菌(10.4%)、鸭沙门菌(8.9%)和鼠伤寒沙门菌及单相变种(8.3%)[109]。中国、欧盟和美国地区猪肉来源的沙门菌优势血清型中均包含鼠伤寒沙门菌及单相变种,但欧盟和美国的其他优势

表4 2008—2023年沙门菌血清型在我国猪肉生产链中的分布情况

Table 4 Related serovars of *Salmonella* in pork production in China from 2008 to 2023 originating from included studies

血清型	猪肉生产链			合计/%
	养殖/%	屠宰/%	零售/%	
德尔卑	278(30.6)	758(34.7)	660(23.0)	1 696(28.4)
鼠伤寒及单相变种	405(44.6)	487(22.3)	581(20.2)	1 473(24.7)
罗森	71(7.8)	309(14.2)	389(13.5)	769(12.9)
伦敦	20(2.2)	69(3.2)	430(15.0)	519(8.7)
火鸡	3(0.3)	94(4.3)	91(3.2)	188(3.2)
阿贡纳	ND	26(1.2)	153(5.3)	179(3.0)
鸭	ND	75(3.4)	91(3.2)	166(2.8)
肠炎	43(4.7)	37(1.7)	17(0.6)	97(1.6)
乌干达	ND	60(2.7)	31(1.1)	91(1.5)
汤卜逊	1(0.1)	26(1.2)	21(0.7)	48(0.8)
印第安纳	11(1.2)	23(1.1)	8(0.3)	42(0.7)
肯塔基	16(1.8)	13(0.6)	12(0.4)	41(0.7)
猪霍乱	21(2.3)	7(0.3)	4(0.1)	32(0.5)
黄金海岸	1(0.1)	3(0.1)	27(0.9)	31(0.5)
斯坦利	5(0.6)	2(0.1)	22(0.8)	29(0.5)
未识别	4(0.4)	4(0.2)	14(0.5)	22(0.4)
其他	29(3.2)	189(8.7)	322(11.2)	540(9.1)
合计	908(15.2)	2 182(36.6)	2 873(48.2)	5 963(100)

注:ND表示未确定数据

血清型与中国存在较大的差异,提示不同地区的血清型分布存在差异,具体见表6。

与患者来源的沙门菌血清型比较发现,鼠伤寒沙门菌及单相变种在中国、欧盟和美国患者中所占比例(13.9%~45.3%)与猪肉中该血清型占比较为一致[6,110]。但我国患者中的德尔卑沙门菌占比(2.2%)相对较低,这与其在猪肉中所占比例(28.4%)存在显著差异(P<0.05)(表7),主要与该类菌株的宿主适应性及致病力相关[111-113]。

2.3 我国猪肉生产链中部分沙门菌抗生素耐药性情况

纳入的11种抗生素包括氨苄西林(Ampicillin,AMP)、环丙沙星(Ciprofloxacin,CIP)、萘啶酸(Nalidixic acid,NAL)、四环素(Tetracycline,TET)、氯霉素(Chloramphenicol,CHL)、阿莫西林(Amoxicillin,AMC)、磺胺甲噁唑(Sulfamethoxazole,SXT)、链霉素(Streptomycin,STR)、多西环素(Doxycycline,DOX)、头孢噻肟(Cefotaxime,CTX)和庆大霉素(Gentamicin,GEN)(表8)。根据耐药率高低,将抗生素分为3类:[Ⅰ(耐药率>50%),Ⅱ(耐药率10%-50%),Ⅲ(耐药率<10%)][114]。第Ⅰ类抗生素包括DOX(85.1%)、TET(78.8%)、AMP(65.1%)和CHL(61.5%);第Ⅱ类抗生素包括SXT(47.7%)、STR(41.4%)、NAL(35.4%)、AMC(32.4%)、GEN(30.0%)和CIP(24.5%);第Ⅲ类抗生素仅有CTX(6.1%)。

第Ⅰ类抗生素中,DOX和TET均属于四环素类抗生素,其耐药率在所有血清型中均高于70%。

表5 2008—2023年沙门菌血清型在我国猪肉生产链中的比例及同比增长情况

Table 5 The proportion and year-on-year growth of *Salmonella* serovars related to the pork production chain in China from 2008 to 2023

血清型	T1/%（2008—2012年）	T2/%（2013—2017年）	T3/%（2018—2023年）	占比情况变化/%		
				T1-T2	T2-T3	T1-T3
德尔卑	267(46.0)	1 200(34.5)	400(18.6)	−11.5	−25.9	−37.4
鼠伤寒及单相变种	81(13.9)	672(19.3)	667(31.0)	5.4	11.7	17.1
罗森	ND	438(12.6)	415(19.3)	12.6	6.7	19.3
伦敦	36(6.2)	219(6.3)	298(13.8)	0.1	7.5	7.6
火鸡	17(2.9)	177(5.1)	2(0.1)	2.2	−5.0	−2.8
阿贡纳	17(2.9)	45(1.3)	6(0.3)	−1.6	−1.0	−2.6
鸭	17(2.9)	74(2.1)	21(1.0)	−0.8	−1.1	−1.9
肠炎	16(2.8)	61(1.8)	55(2.6)	−1.0	0.8	−0.2
汤卜逊	1(0.2)	28(0.8)	22(1.0)	0.6	0.2	0.8
印第安纳	5(0.9)	33(0.9)	4(0.2)	0.0	−0.7	−0.7
其他	124(21.3)	527(15.2)	263(12.2)	−6.1	−3.0	−9.1
总计	581(100.0)	3 474(100.0)	2 153(100.0)	0	0	0

注：ND表示未确定数据

表6 中国、欧盟和美国猪源沙门菌血清型比较

Table 6 Comparison of dominant *Salmonella* serovars in China, European Union and the United States pork

中国			欧盟			美国		
血清型	数量	所占比例/%	血清型	数量	所占比例/%	血清型	数量	所占比例/%
德尔卑	1 696	28.4	鼠伤寒及单相变种	508	47.7	婴儿	133	10.4
鼠伤寒及单相变种	1 473	24.7	德尔卑	255	24.0	鸭	114	8.9
罗森	769	12.9	婴儿	52	4.9	鼠伤寒及单相变种	106	8.3
伦敦	519	8.7	罗森	51	4.8	德尔卑	92	7.2
火鸡	188	3.2	勃兰登堡	25	2.3	埃科	86	6.7
阿贡纳	179	3.0	吉韦沙门菌	16	1.5	约翰内斯堡	84	6.6
鸭	166	2.8	猪霍乱	14	1.3	伦敦	64	5.0
肠炎	97	1.6	肠炎	12	1.1	乌干达	59	4.6
乌干达	91	1.5	利奇菲尔德	11	1.0	阿贡纳	41	3.2
汤卜逊	48	0.8	伦敦	10	0.9	渥兴顿	21	1.6
其他	737	12.4	其他	110	10.3	其他	476	37.3
总计	5 963	100	总计	1 064	100	总计	1 276	100

表7 中国、欧盟和美国人源沙门菌血清型分布及比例

Table 7 Distribution and proportion of human *Salmonella* serovars in China, European Union and the United States

中国（2014—2021年）			欧盟（2020—2022年）			美国（2020—2022年）		
血清型	数量	所占比例/%	血清型	数量	所占比例/%	血清型	数量	所占比例/%
鼠伤寒及单相变种	15 672	45.3	肠炎	77 790	56.3	肠炎	3 173	16.5
肠炎	7 877	22.7	鼠伤寒及单相变种	31 277	22.6	鼠伤寒及单相变种	2 671	13.9
伦敦	1 221	3.5	德尔卑	3 228	2.3	纽波特	2 131	11.1
斯坦利	1 167	3.4	纽波特	1 527	1.1	爪哇纳	1 415	7.4
德尔卑	770	2.2	婴儿	1 222	0.9	婴儿	603	3.1
罗森	758	2.2	那波利	1 212	0.9	奥雷宁堡	511	2.7
汤卜逊	569	1.6	科隆	1 138	0.8	圣保罗	454	2.4
阿贡纳	479	1.4	彻斯特	800	0.6	密西西比	436	2.3
黄金海岸	447	1.3	病牛	796	0.6	汤卜逊	428	2.2
肯塔基	283	0.8	勃兰登堡	715	0.5	慕尼黑	428	2.2
其他	5 388	15.6	其他	18 511	13.4	其他	6 987	36.3
总计	34 631	100.0	总计	138 216	100.0	总计	19 237	100.0

四环素类抗生素在猪肉生产中被广泛应用，常占抗生素总用量的50%以上[115-116]。TET自1948年起用于临床治疗，根据2013年一项抗生素使用分析报告，其在中国肉猪中的使用量为47.5%[117]。此外，TET的耐药性基因通常位于质粒等可移动遗传元件上[118]，这也是其耐药率较高的原因之一。AMP和CHL由于价格低廉且具有广谱抗菌活性，因此在养殖业中得到广泛使用[119-121]。这些抗生素的高耐药率不仅出现在猪肉源沙门菌中，也普遍存在于中国和美国的鸡肉和牛肉源沙门菌中[122-125]。第Ⅱ类抗生素中，NAL和CIP分别为喹诺酮类和氟喹诺酮类抗生素。由于喹诺酮类抗生素的广泛使用，沙门菌的耐药率逐年上升。而氟喹诺酮类抗生素在猪肉生产中的使用量已达到28.7%[117]，并且在多个国家的猪肉生产中占据较高比例[126-127]。在SXT、STR、AMC和GEN中，STR和GEN属于氨基糖苷类抗生素，因其具有广泛的抗菌谱和较强的杀菌活性等特点，在动物和人类中均得到广泛应用[128]。第Ⅲ类抗

表8 2008—2023年德尔卑沙门菌、鼠伤寒沙门菌及单相变种、肠炎沙门菌、伦敦沙门菌和罗森沙门菌在我国猪肉生产链中的耐药特征

Table 8 Drug resistance of *S.* Derby, *S.* Typhimurium and *S.* 4,[5],12:i:-, *S.* Enteritidis, *S.* London, and *S.* Rissen in the pork production chain in China from 2008 to 2023

血清型	采样阶段	耐药数量/总数量(%)										
		氨苄西林(AMP)	环丙沙星(CIP)	萘啶酸(NAL)	四环素(TET)	氯霉素(CHL)	阿莫西林(AMC)	复方新诺明(SXT)	链霉素(STR)	多西环素(DOX)	头孢噻肟(CTX)	庆大霉素(GEN)
德尔卑	养殖(*n*=32)	4/32	1/28	8/28	23/32	—	—	5/28	—	—	—	1/28
	屠宰(*n*=111)	42/92	14/84	25/97	96/105	43/44	—	40/90	22/53	1/6	—	6/84
	零售(*n*=72)	22/45	1/44	24/49	42/71	13/44	3/41	20/71	15/66	1/1	—	3/44
	总计(215)	68/169 (40.2)	16/156 (10.3)	57/174 (32.8)	161/208 (77.4)	56/88 (63.6)	3/41 (7.3)	65/189 (34.4)	37/119 (31.1)	2/7 (28.6)	—	10/156 (6.4)
鼠伤寒及单相变种	养殖(*n*=24)	21/24	14/22	12/22	16/22	—	9/9	9/9	—	—	—	9/9
	屠宰(*n*=59)	46/59	4/26	27/55	39/55	13/44	1/2	19/41	7/24	4/4	1/24	19/41
	零售(*n*=56)	33/42	14/25	17/42	46/55	35/42	8/13	31/52	32/52	1/1	1/3	20/55
	总计(139)	100/125 (80.0)	32/73 (43.8)	56/119 (47.1)	101/132 (76.5)	48/86 (55.8)	18/24 (75.0)	59/102 (57.8)	39/76 (51.3)	5/5 (100.0)	2/27 (7.4)	48/105 (45.7)
肠炎	养殖(*n*=3)	3/3	2/3	2/3	1/3	—	1/3	1/3	—	—	—	—
	屠宰(*n*=7)	3/7	0/1	6/7	0/1	0/1	—	—	—	—	—	0/1
	零售(*n*=9)	6/9	3/9	6/9	1/9	6/9	—	—	—	—	0/3	3/3
	总计(*n*=19)	12/19 (63.2)	5/13 (38.5)	14/19 (73.7)	2/13 (15.4)	6/10 (60.0)	1/3 (33.3)	1/3 (33.3)	—	—	0/3 (0)	3/4 (75.0)
伦敦	屠宰(*n*=37)	36/37	23/30	—	37/37	36/37	—	34/37	7/7	—	—	34/37
	零售(*n*=16)	9/16	0/3	0/3	6/10	4/10	—	5/13	1/7	5/6	0/3	3/3
	总计(53)	45/53 (84.9)	23/33 (69.7)	0/3 (0)	43/47 (91.5)	40/47 (85.1)	—	39/50 (78.0)	8/8 (100.0)	5/6 (83.3)	0/3 (0)	37/40 (92.5)
罗森	屠宰(*n*=77)	45/49 (91.8)	3/47 (6.4)	1/47 (2.1)	69/77 (89.6)	21/47 (44.7)	—	—	—	45/49 (91.8)	—	2/28 (7.1)
总计耐药率(%)	全生产链(*n*=503)	270/415 (65.1)	79/322 (24.5)	128/362 (35.4)	376/477 (78.8)	171/278 (61.5)	22/68 (32.4)	164/344 (47.7)	84/203 (41.4)	57/67 (85.1)	2/33(6.1)	100/333 (30.0)

注:-无数据

生素 CTX 的耐药率相对较低(6.1%),在中国猪肉生产中的使用量仅占 0.17%[117]。

通过对血清型相关抗生素耐药性的比较发现,大部分抗生素的耐药率呈上升趋势(表 9)。AMP、SXT、TET 和 CIP 在不同时间段的耐药率分别增长了 38.3%、28.2%、18.0% 和 15.1%,尤其在 T2-T3 时间段内,SXT、AMP、TET 和 CIP 的耐药率分别增长了 48.2%、34.0%、21.7% 和 12.6%。20 世纪 80 年代,研究发现沙门菌 DT104 携带多重耐药基因岛 SGI1,赋予细菌对 AMP、CHL、STR、SXT 和 TET 的耐药性,这种耐药模式被称为 ACSSuT 耐药模式[129-132]。在中国河南省的研究中同样发现了猪源沙门菌中存在 ACSSuT 耐药模式[133],该现象不仅影响养殖业,还会威胁到公共卫生安全。

此外,与欧盟和美国的研究相比,我国猪肉源沙门菌的耐药率普遍较高[6,102](表 10)。以 TET 为例,中国猪肉沙门菌耐药率为 74.8%,而欧盟和美国分别为 31.3% 和 68.1%。NAL 在中国猪肉生产链沙门菌中的耐药率为 40.7%,而在欧盟和美国仅为 6.7% 和 4.4%。欧盟和美国已分别于 2006 年和 2005 年禁止在畜牧业中使用喹诺酮类药物,这可能是其耐药率较低的原因[134-135]。此外,CTX 在欧盟(0.4%)和美国(4.2%)中耐药率同样较低,而在中国猪肉生产链沙门菌中为 6.1%(表 8)。欧盟于 2006 年禁止 CTX 作为生长促进剂添加在动物饲料中[136],2012 年美国兽医协会同样禁止头孢菌素类抗生素在猪中使用[137]。

总体而言,中国、欧盟和美国猪肉沙门菌抗生素耐药情况不容乐观,虽然中国猪肉沙门菌数据来源于多个年份和省份,方法不统一和变更可能导致一定的数据偏移,但整体污染率仍不容乐观。这种情况在全球范围内蔓延,严重威胁到我们应对常见传染病的治疗能力,并对人类健康构成潜在威胁。因此,必须加强细菌耐药性监测与防控工作,并推动实施更加合理的抗生素使用政策。

3 小结

本研究系统分析了中国 2008—2023 年猪肉生产链的各个阶段分离出沙门菌的污染率、血清型以及耐药特征等。结果显示,中国猪肉生产链养殖、屠宰和零售环节中沙门菌的污染率较高,而在实施了沙门菌控制计划后欧盟和美国其污染率明显降

表9 2008—2023年血清型相关抗生素在我国猪肉生产链中不同时间阶段的耐药特征

Table 9 Study on the resistance of serovar-related antibiotics in the pork production chain in China at different time stages from 2008 to 2023

血清型	耐药数量/总数量(%)																				
	氨苄西林AMP			环丙沙星CIP			四环素TET			氯霉素CHL			复方新诺明SXT			链霉素STR			庆大霉素GEN		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
德尔卑	26/76 (34.2)	17/66 (25.8)	28/31 (90.3)	2/72 (2.8)	3/53 (5.7)	11/31 (35.5)	79/100 (79.0)	48/59 (81.4)	30/31 (96.8)	26/57 (45.6)	—	30/31 (96.8)	24/83 (28.9)	9/53 (17.0)	28/31 (90.3)	12/44 (27.3)	22/53 (41.5)	—	4/72 (5.6)	2/53 (3.8)	4/31 (12.9)
鼠伤寒及单相变种	49/58 (84.5)	61/80 (76.3)	—	15/24 (62.5)	22/62 (35.5)	—	47/56 (83.9)	53/76 (69.7)	—	25/32 (78.1)	31/49 (63.3)	—	31/43 (72.1)	21/60 (35.0)	—	6/17 (35.3)	27/46 (58.7)	—	30/43 (69.8)	13/49 (26.5)	—
肠炎	5/8 (62.5)	7/10 (70.0)	—	2/3 (66.7)	3/11 (27.3)	—	1/3 (33.3)	2/10 (20.0)	—	—	6/10 (60.0)	—	—	—	—	—	4/7 (57.0)	—	—	4/5 (80.0)	—
伦敦	1/7 (14.3)	15/16 (93.8)	29/30 (96.7)	—	0/3(0)	23/30 (76.7)	3/7 (42.9)	10/10 (100)	30/30 (100)	1/7 (14.3)	10/10 (100)	29/30 (96.7)	1/7 (14.3)	10/13 (76.9)	28/30 (93.3)	1/7 (14.3)	7/7 (100)	—	—	10/10 (100)	27/30 (90.0)
罗森	—	2/2 (100)	43/47 (91.5)	—	—	3/47 (6.4)	—	25/30 (83.3)	44/47 (93.6)	—	—	21/47 (44.7)	—	2/2 (100)	43/47 (91.5)	—	—	—	—	2/28 (7.1)	5/47 (10.6)
总计	81/149 (54.3)	102/174 (58.6)	100/108 (92.6)	19/99 (19.2)	28/129 (21.7)	37/108 (34.3)	130/166 (78.3)	138/185 (74.6)	104/108 (96.3)	26/39 (66.7)	47/69 (68.1)	50/77 (64.9)	32/50 (64.0)	33/75 (44.0)	71/77 (92.2)	7/24 (29.2)	38/60 (63.3)	—	30/43 (69.8)	29/92 (31.5)	32/77 (41.6)

注:—无数据;T1:2008—2012、T2:2013—2017、T3:2018—2023

表10 德尔卑沙门菌、鼠伤寒沙门菌及单相变种、肠炎沙门菌在中国、欧盟和美国猪肉来源沙门菌中的耐药特征

Table 10 Drug resistance of *S*. Derby,, *S*. Enteritidis, *S*. Typhimurium and *S*. 4,[5],12:i:- in *Salmonella* originating from pork in China, the United States and the European Union

国家	血清型	耐药数量/总数量(耐药率/%)										
		氨苄西林 AMP	环丙沙星 CIP	萘啶酸 NAL	四环素 TET	氯霉素 CHL	阿莫西林 AMC	复方新诺明 SXT	链霉素 STR	多西环素 DOX	头孢噻肟 CTX	庆大霉素 GEN
中国	德尔卑	68/169	16/156	57/174	161/208	56/88	3/41	65/189	37/119	2/7	—	10/156
	肠炎	12/19	5/13	14/19	2/13	6/10	1/3	1/3	—	—	0/3	3/4
	鼠伤寒及单相变种	100/125	32/73	56/119	101/132	48/86	18/24	59/102	39/76	5/5	2/27	48/105
	总计(n=359)	180/313(57.5)	53/242(21.9)	127/312(40.7)	264/353(74.8)	110/184(59.8)	22/68(32.4)	125/294(42.5)	76/195(39.0)	7/12(58.3)	2/30(66.7)	61/265(23.0)
欧盟	德尔卑	38/371	13/371	11/371	73/371	13/371	—	—	—	—	2/371	5/371
	肠炎	—	—	—	—	—	—	—	—	—	—	—
	鼠伤寒及单相变种	112/163	24/163	25/163	94/163	52/163	—	—	—	—	0/163	13/163
	总计(n=7 202)	150/534(28.1)	37/534(6.9)	36/534(6.7)	167/534(31.3)	65/534(12.2)	—	—	—	—	2/534(0.4)	18/534(3.4)
美国	德尔卑	1/48	1/48	2/48	33/48	1/48	—	—	15/48	—	—	0/48
	肠炎	0/1	0/1	1/1	0/1	0/1	—	—	—	—	1/24	0/1
	鼠伤寒及其单相变种	38/86	3/86	3/86	59/86	25/86	—	—	33/62	—	—	4/86
	总计(n=135)	39/135(28.9)	4/135(3.0)	6/135(4.4)	92/135(68.1)	26/135(19.3)	—	—	48/110(43.6)	—	1/24(4.2)	4/135(3.0)

注:-无数据

低，这表明在猪肉生产链中采取沙门菌控制措施对于减少食源性疾病有着重要的意义。我国已出台了《生猪屠宰检疫规范》等相关文件以加强在猪肉屠宰环节的监控[96]。在此基础上，建议继续开展猪肉基线监测数据的收集与分析，并进行风险评估，以全面了解猪肉产品中致病微生物的存在及其潜在风险。同时，应根据我国的生产实际情况和食品安全要求，制定相适应的卫生指标及致病微生物的检出限量标准。这将有助于提高猪肉产品质量控制水平，确保其符合食品安全标准，进而保障消费者的健康与安全[138]。

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