食品中磺胺类药物检测方法研究进展

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摘 要: 磺胺类兽药残留是目前重要的动物源性食品安全问题, 检测食品中磺胺类兽药残留对人体健康具有重要的意义。本文凝练了近 5 年食品中磺胺类药物残留检测的通用前处理方法及其原理。研究发现, 食品中磺胺类药物的检测, 其前处理方法具有显著共性特征。具体体现在: 磺胺类药物前处理操作的原理和步骤可以在具有相同或相似基质特征的食品之间相互借鉴, 得到磺胺检测方法通式, 从而有助于提高检测效率。不同的前处理方法相应满足高通量、高灵敏度或操作简便等不同的检测需求。此外, 本文还介绍了磺胺类药物残留检测前处理的新技术, 结合实际情况分析了这些新技术的可行性, 并对新技术方法与目前常用技术方法之间的灵敏度进行了比较。最后, 文章对磺胺类药物残留检测技术的研究方向进行了展望。

关键词: 磺胺; 前处理; 质谱; 食品

Research progress on detection of sulfonamides in food

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ABSTRACT: Sulfonamides residues are important animal-derived food safety problems. It is of great significance for human health to detect the sulfonamides residues in food. First of all, the general pretreatment methods and principles of sulfonamides residues detection in food in recent 5 years were condensed. The results showed that the pretreatment methods of sulfonamides in food had obvious common characteristics. The common characteristics embodied in that general formula of sulfonamides detection methods would be possible to be made under the same or similar matrix between the characteristics of food by their principle and procedure of pretreatment operation in sulfonamides, which was helpful to improve the detection efficiency. Different pretreatment methods met different requirements such as high throughput, high sensitivity, and high efficiency, respectively. Additionally, this paper introduced new pretreatment techniques for the detection of sulfonamides, analyzed the feasibility of the new technology combined with the actual situation, and compared the advantages of sensitivity between new technology and the common technology. Finally, the research direction of sulfonamides residues detection technology was discussed.

KEY WORDS: sulfonamides; pretreatment; mass spectrum; food

1 引 言

食品中的兽药残留近些年持续受关注[1]。磺胺类药物(sulfonamides, SAs)属于化学合成抗菌药, 是一类含有对氨基苯磺酰胺结构药物的总称, 具有抗菌谱广、疗效确定、方便安全等特点[2]。磺胺类药物作为抗生素使用已有 70 多年的历史, 可以由生物体内代谢进入食物链[3]。由于磺胺类药物的使用量远高于该类药物的代谢量, 使得该药物在

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生物体内含量逐渐升高[4]。因此, 磺胺类兽药残留量的监测数据是我国食品常规检测项目。在我国, 食品中磺胺总量最高残留限值为 100 μg/kg, 这与国际上磺胺限量的标准相同。

食品中磺胺的检测方法根据基质不同, 净化的方式分为 2 种。一种是充分提取待测物质后, 剔除提取液中的干扰组分, 如 QuEChERS(quick, easy, cheap, effective, rugged, safe)方法; 另一种是利用极性差异、形似相溶、分子间作用力等原理, 将提取液中的待测组分进行萃取以达到提纯的目的, 如使用固相萃取(solid-phase extraction, SPE)净化柱。每种方法适用于何种食品基质, 要根据灵敏度需求, 满足检测技术手段综合考虑。在磺胺类药物残留的检验工作中, 快速准确的制备样品包括以下内容: (1)如何缩短样品制备流程以提高回收率; (2)能否通过降低样品分析的质量基数减低干扰和污染以延长色谱柱和仪器的使用寿命; (3)是否能够有效降低有机试剂的使用量, 即提高有机试剂的提取效率使分析方法更环保; (4)如何与其他兽药同时提取以实现高通量检测提高检测效率; (5)如何促进样品前处理自动化处理的发展以促进检测时效。本文综述了近 5 年牛奶、蛋类、肉类、蜂蜜、水产品和婴幼儿食品基质中磺胺类药物的前处理方法, 凝练了近 5 年来磺胺类药物残留检测前处理方法的技术公式, 总结了磺胺类药物残留检测前处理新技术, 讨论了磺胺类药物残留检测前处理技术的研究方向。期待能为食品一线检测同行提供样品制备优化方案。

2　磺胺类药物的特性与分类

磺胺类化合物有上万种, 磺胺类物质的化学式见图 1。目前应用在药品和兽药中的有 40 多种, 常见常见 18 种磺胺类药物的中英文名称见表 1。

磺胺类化合物的衍生物均是由 R 基不同而命名。多数发挥功效的磺胺具有杂环自由基, 比如嘧啶, 哒嗪。如果氨基上的氢原子被其他自由基取代, 磺胺就失去了其抗生素的能力。如果磺胺进入人体之后, 自由基建存, 其抗生素能力被保持, 磺胺的取代基将增加或降低磺胺抗生素能力[5]。

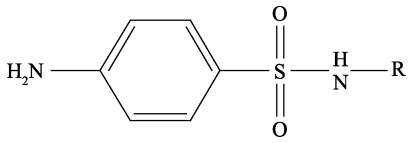

图 1　磺胺类药物化学式

Fig. 1　Chemical formula of sulfanilamides

所有的磺胺类物质均呈淡黄色无味的粉末, 味苦。磺胺几乎不溶于水。其酸碱性由其苯环上的氨基解离状态决定, 其溶液可能是酸性, 中性也可能是碱性[6]。

3　磺胺类药物分析前处理方案

乙腈是提取磺胺类药物时最常用到的提取溶剂, 应用在肉基质、鱼、蜂蜜、婴幼儿食品的提取中。还有文献中使用甲醇、乙酸乙酯、二氯甲烷作为提取液, 乙腈和氯仿混合液, 水与磷酸混合液, 添加二甲亚砜的甲醇和水混合液[7]。提取的辅助操作有超声和微波, 超声使用的最多。据报道, 相比于甲醇、丙酮、醋酸钠缓冲液, 提取效率最高的是纯乙腈溶剂。提取过程使用正己烷去除基质中的脂肪, 利用固相萃取小柱进行提纯。常用到 C_{18} 净化柱, 影响其吸附的主要因素是磺胺的极性与其分子的缔合作用强弱。实验证明, 磺胺类药物能够在 C_{18} 净化柱上得到满意的回收[8]。样品前处理的通式: (1)将搅碎研磨混合均匀的样品定量, 加入提取试剂超声辅助, 使待测组分充分提取; (2)离心, 过滤, 去除食品杂质; (3)利用净化小柱提取待测组分, 洗脱液浓缩; (4)复溶待仪器检测。。

表 1　常见 18 种磺胺类药物的中英文名称

Table 1　Chinese and English names of 18 kinds of common sulfonamides

中文名	英文名称(缩写)	中文名	英文名称(缩写)
磺胺醋酰	Sulfacetamide(SAA)	磺胺甲二唑	Sulfamethizole(SMT)
对氨基苯磺酰胺	Sulfanilamide(SAM)	磺胺甲嘧啶	Sulfamethazine(SMZ)
磺胺氯哒嗪	Sulfachloropyridazine(SCP)	磺胺吡啶	Sulfapyridine(SPY)
磺胺间二甲氧基嘧啶	Sulfadimethoxine(SDM)	磺胺喹恶啉	Sulfaquinoxaline(SQX)
磺胺二甲嘧啶	Sulfadimidine(SDD)	磺胺异恶唑	Sulfisoxazole(SSA)
磺胺邻二甲氧嘧啶	Sulfadoxine(SDO)	水杨酸偶氮磺胺吡啶	Sulfasalazine(SSZ)
磺胺嘧啶	Sulfadiazine(SDZ)	磺胺噻唑	Sulfathiazole(STZ)
磺胺甲氧哒嗪	Sulfamethoxypyridazine (SMP)	磺胺甲恶唑	Sulfamethoxazole(SMX)
磺胺甲基嘧啶	Sulfamerazine(SMR)	磺胺甲氧噻二唑	Sulfametrole(SML)

3.1 常用提取方法

近年来, 样品前处理以高通量检测多种药物残留为研究方向。对磺胺类药物的分离和提取使用的方法还包括压力液相萃取[9](pressurized liquid extraction, PLE)、分散性固相基质(matrix solid-phase dispersion, MSPD)以及 QuEChERS 方法。

压力液相萃取技术特点是高效、自动化程度高。样品的前处理过程在压力下进行, 实行全自动待测样提取。有机试剂、水溶液均可应用此方法, 该方法实现了溶剂提取效率最大化。系统温度的升高和系统压力的升高都有利于磺胺的提取。目前, 这种前处理方法实现应用的食品基质有: 肉类、鱼以及禽蛋。

分散性固相基质法于 1989 年出现。该方法适用于固体、脂肪含量高或低具有粘性的食品。样品前处理的通式: (1)样品与吸附剂充分混合; (2)研钵中充分均质化转移至离心管; (3)洗脱待测组分; (4)正己烷提取脂肪, 使待测组分被净化。分散性固相基质法适用于肉和鱼。处理过程中可以选用不同的吸附剂和提取剂。吸附剂一般选用二氧化硅, 硅藻土或者中性氧化铝。提取剂一般用甲醇、正己烷、二氯甲烷、乙腈、丙酮。据报道, 硅藻土/丙酮组合是相对效率最高的组合。也有使用 C_{18} 作为吸附剂, 以乙腈+二氯甲烷(1:1, *V*: *V*)或碳纳米管作为吸附剂, 50 mmo/L 醋酸铵溶液(95:5, *V*: *V*)为提取剂。

QuEChERS 方法最先出现在 2003 年, 当时主要为了处理水果和蔬菜中的农药残留。该方法有 2 个主要的步骤。第一个步骤是利用盐析的方法, 在有机相和水相之间提取待测物; 第二个步骤是用 SPE 分散, 过程中用无水 $MgSO_4$ 进行清理, 吸附剂选择 C_{18} 或者 N-丙基乙二胺(primary secondary amine, PSA)。QuEChERS 方法很高效, 但需要进行改进和微调才能适应不同种类食品基质下磺胺的检测。几种常见制备方法的优劣比较见表 2。

3.2 提取新方法

液液萃取更适用于牛奶和蜂蜜中提取磺胺。萃取试剂可选择乙酸乙酯、氯仿: 丙酮(65:35, *V*:*V*)、乙腈、正己烷。自 2006 年开始萃取技术正向着微萃取(dispersive LLME, DLLME)方向发展。微萃取技术主要是应用了亚微米级的萃取乳液, 萃取乳液增大了质子交换的表面积, 能够有效缩短分析提取的时间。这种萃取技术达到分配平衡的时间不超过 1 min。微萃取方法中萃取剂的应用可以多样化, 水溶液和有机试剂, 极性或非极性有机试剂均能够使用。样品提取剂和分散剂加入离心管中, 经过摇匀和震荡达到乳化后离心既能获得所需待测物的提取液, 可利用超声或增强溶液离子强度的方式以加速分散剂的乳化效果, 加快处理能力, 提高提取效率。

利用溶剂提取肉、鱼、禽蛋、蜂蜜、牛奶等食品中的磺胺类物质常常伴随使用 SPE 柱。目前市面上升级并更新的集成化净化小柱, 如: Oasis MCX、Oasis HLB、Nexus Abselul、BondElut SCX、Cleanert PEP、Strata SCX、LiChrolut C_{18}、HySpereC_{18} HD、Sep-Pak C_{18} 等。乙腈、甲醇、氨基乙腈、氨基甲醇、酸化乙腈、酸化甲醇、酸化甲醇和乙腈的混合液常用作活化剂。毛细管整体柱可与 SPE 柱交替使用。毛细管整体柱的优势在于其能添加到在线预处理系统。

新技术固相微萃取(solid-phase microextraction, SPME)比传统方法更满足高效这一需求。与 LLME 和 SPE 相比较, SPME 试剂消耗少, 目标化合物分析的有效性提高。SPME 用了不同的固相聚合材料(聚二甲基硅氧烷丙烯酸酯和聚乙二醇/二乙烯基苯等)。为了提高分离的选择性和效率, 吸附材料也在进行不断创新, 比如碳纳米材料和分子印迹的使用。Chen 等[18]应用该处理方法从牛奶中分离提取的磺胺待测物直接用紫外检测器毛细管电泳分析获得了回收率 89%~110%的结果。从牛奶和肉中提取磺胺, 利用甲基丙酸烯和甲基丙烯酸乙二醇酯填料萃取柱能够实现有效分析[19]。利用渗透膜、固相萃取柱的有效净化, 30 mg 的水溶性聚乙烯(羟乙基-甲基丙烯酸基质)能够实现有效分离牛奶中的磺胺类物质[20]。

表 2 几种样品制备方法比较

Table 2 Comparison of several sample preparation methods

提取方法名称	优势	不足	相关文献
低温快速分离液液萃取(liquid-liquid extraction with fast partition at very low temperature, LLE-FPVLT)	较低溶剂使用量。不用额外的净化处理。	需要液氮, 操作需要特殊注意	[10,11]
加压液相萃取(pressurized liquid extraction, PLE)	提取效率较高, 自动化程度较高, 可以用水最为提取试剂	高压条件需要配套的实验条件, 设备的额外保养费用增加	[9]
分散性固相基质提取(MSPD)	更有利于粘性较大的样品提取	需要净化或提纯	[12,13]
QuEChERS	操作简单, 快速, 成本低	部分待测组分选择性不佳	[14,15]
分散性液液微萃取(dispersive liquid-liquid microextraction, DLLME)	快速, 高效	需要额外的溶剂	[16,17]

表 3 质谱方法检测磺胺实例

Table 3　Mass spectrometric detection of sulfonamides

种类	基质	方法	检测方法	液相色谱柱	流动相	LODs	参考文献
		提取与净化					
16	猪瘦肉	甲醇提取，离心，液氮低温萃取(-20 ℃, 12 h)富集，去除溶剂，酸化溶液复溶 LLE-FPVLT (liquid–liquid extraction with fast partitionat very low temperature)无需净化	HPLC-MS/MS	Zorbax Eclipse XDB C_{18} (4.6 mm×150 mm, 5 mm)	A: 含 0.1%甲酸的 5%乙腈水 B: 含 0.1%甲酸的 95%乙腈水	0.30~6.29 μg/kg	[21]
4	猪瘦肉、牛瘦肉	0.1 mol EDTA(ethylenediaminete-traacetic acid)均质+70%甲醇提取后上机无需净化	HPLC-MS/MS	Genesis C_{18} (50 mm×2.1 mm, 4 μm)	A: 含 0.2%甲酸、0.1 mmol/L 草酸的水溶液 B: 100%乙腈	1~3 μg/kg	[22]
18	肉类、禽蛋	0.1%甲酸乙腈提取 HLB 的 SPE 柱净化	UHPLC-QTOF MS	Agilent Zorbax Eclipse XDB C_{18}(3.0 mm×100 mm, 1.8 μm)	A: 含 0.1% 甲酸 5 mmol/L 甲酸铵水 B: 0.1% 甲酸乙腈	肉: 0.08~1.48 μg/kg; 蛋: 0.03~0.83 μg/kg; 奶: 0.1~1.26 μg/kg	[23]
16	肉类、禽蛋、蜂蜜	乙腈提取，乙腈/水 (25:75, *V*:*V*)复溶	UHPLC-MS/MS	Acquity UPLC HSS T3 (150 mm×2.1 mm, 1.7 μm)	A: 0.05%甲酸水 B: 0.05%甲酸乙腈	5 μg/kg	[24]
18	肉类	Na_2EDTA 乙腈/甲醇(5:1, *V*:*V*)	UPLC-MS/MS	Acquity HSS-T 3 (100 mm × 2.1 mm, 1.8 μ m)	A: 0.1%甲酸水 B: 0.1%甲酸甲醇	LOQs: 0.5~2.0 μg/kg	[25]
21	牛肾	乙腈水(4:1, *V*:*V*)提取 C_{18} 吸附剂，正己烷净化	LC-MS/MS	Prodigy ODS-3 (3.0 m×150 mm, 5 μm)	A: 0.1%甲酸水 B: 0.1% 甲酸甲醇	The lowest calibrated level (LCL): 1~50 ng/g	[26]
12	牛肉、牛奶	甲醇/水(80:20, *V*:*V*)提取，免疫亲和色谱提纯	UPLC MS/MS	Acquity BEH C_{18}(100 mm×2.1 mm, 1.7 μm)	A: 0.1%甲酸水 B: 甲醇	牛肉: 1.6~8.0 μ g/kg; 牛奶: 1.8~6.4 μ g/kg	[27]
16	鸡肉	0.1%甲酸乙腈 NH_2 和无水 Na_2SO_4 固相散装吸附剂(DSPE)，过滤旋蒸，乙腈水复溶(90:10, *V*:*V*)	HPLC-MS/MS	Phenomenex Synergi Fusion-RP (100 mm×2 mm, 2.5μm)	A: 0.1%甲酸水 B: 乙腈	Sulfaguanidine CC*α*: 10.1 μg/kg; Sulfaguanidine CC*β*: 17.2 μg/kg; CC*α*: 105~111 μg/kg; CC*β*: 110~122 μg/kg	[28]
6	鸡肉	乙腈/水(80:20, *V*:*V*) 柠檬酸钠，无水 $MgSO_4$，DSPE 和 PSA，过滤，乙腈水复溶(1:1, *V*:*V*)	UHPLC-MS/MS	Acquity UHPLC BEH C_{18} (100 mm×2.1 mm, 1.7 μm)	A: 0.1%甲酸乙腈 B: 0.1%甲酸水	3.2~6.4 μg/kg	[29]
15	猪肝	乙腈提取辅助盐析，乙腈/二氯甲烷/水溶液复溶	HPLC-MS/MS	Zorbax SB C_{18}(250 mm×4.6 mm, 5μm)	A: 0.1%甲酸-5%乙腈水 B: 0.1%甲酸-95%乙腈水	5.58~16.75μg/kg	[10]
18	猪肉	SPE 配合磁性分子印迹 乙腈: 50 mmol 醋酸铵(95:5, *V*:*V*)复溶	UHPLC–ESI-MS/MS	Acquity BEH C_{18}(100 mm×2.1 mm, 1.7 μm)	A: 0.2%甲酸水 B: 甲醇	CCα: 103~114 μg/kg CCβ: 112~12 9μg/kg	[30]

续表 3

种类	基质	方法 提取与净化	检测方法	液相色谱柱	流动相	LODs	参考文献
18	猪肝	pressurized liquid extraction(PLE) 乙腈 SPE, HLB 柱净化	UHPLC–MS/MS	Zorbax SB C_{18}(250 mm×4.6 mm, 5 μm)	A: 乙腈 B: 0.1%甲酸水	LODs: 3 μg/kg; LOQs: 10 μg/kg	[31]
10	猪肉、鸡肉	乙腈提取, monolith 基质磁力吸附提取	HPLC-MS/MS 6490 (Agilent)	Kinetex C_{18}(100 mm×3 mm, 2.6 μm)	A: 水 B: 0.1%乙腈	猪肉: 1.2~6.1 ng/kg; 鸡肉: 2.0~14.6 ng/kg	[32]
16	猪肉	乙腈提取, 正己烷除脂肪, 无水硫酸钠除水, SPE 柱净化	LC–MS/MS	ZORBAX Eclipse XDB-C_8 (150 mm×4.6 mm, 5 μm)	A: 0.15%甲酸水 B: 乙腈 C: 甲醇	LOQs: 1.0 μg/kg	[33]
23	猪肉、鸡肉、鱼类、蜂蜜、牛奶	用到 SETMIT SEP/MAC, 类似 QuEChERS 方法	LC–QqLIT	Agilent Zorbax Eclipse AAA(150 mm×4.6 mm, 3.5 μm)	A: 0.02%甲酸水 B: 0.02%甲酸乙腈	LOQs:1.0~7.5 μg/kg	[34]
17	鱼	0.05%酸化甲醇/乙腈(50:50, *V*:*V*)	UHPLC-MS/MS	Zorbax Eclipse Plus C_{18} (2.1 mm×50 mm, 1.8 μm)	A: 乙腈 B: 0.1%甲酸水	LODs: 5.65~14 μg/kg LOQs: 17.8~72.7 μg/kg	[35]
4	鱼	0.1%酸化乙腈/水(80:20, *V*:*V*) 沉淀, 离心后取上清液过滤后上机	UHPLC-QTOF-MS	Acquity UHPLC BEH C_{18} (2.1 m×100 mm, 1.7 μm)	A: 0.01% 甲酸-0.1 mmol/L 乙酸铵水 B: 0.01% 甲酸-0.1 mmol/L 乙酸铵水甲醇	The screening detection limit (SDL): 20μg/kg limit of identification (LOI): 100 μg/kg	[36]
8	鲶鱼	酸化甲醇 在线 SPE 柱净化	HPLC-MS/MS	Synergy Max (150 mm×4.6 mm, 4 μm)	A: 乙腈 B: 0.1%甲酸水	LODs: 38.6~83.9 ng/kg LOQs: 1.5~2.4 μg/kg	[37]
13	鱼	酸化(0.1%甲酸)乙腈	HPLC-MS/MS	Hypersil GOLD Phenyl (50 mm×2.1 mm, 3 μm)	A: 0.1%甲酸乙腈 B: 0.1%甲酸水	0.071~4.6 μg/kg	[38]
15	鱼类、禽蛋	乙腈/水(6:4, *V*:*V*) StrataX SPE 净化, 乙腈复溶	UHPLC-MS	Acquity UPLC BEH C18(100 mm ×2.1 mm, 1.7 μm)	A: 乙腈 B: 0.1%甲酸水	CC*β*:119~198 μg/kg	[39]
7	鱼	乙腈/甲醇(75:25, *V*:*V*) 无水 $MgSO_4$ 和 NaAc, 旋蒸过滤, 酸化乙腈水复溶(1:1, *V*:*V*)	UHPLC-MS/MS	Acquity UHPL CBEH C_{18} (100 mm×2.1 mm, 1.7 μm)	A: 0.1%甲酸乙腈 B: 0.1%甲酸水	LODs: 3.0~7.5 μg/kg LOQs: 10.0~25.0 μg/kg	[40]
7	基围虾	酸化乙腈 无水 $MgSO_4$ 和 NaAc, DSPE 和 PSA,过滤, 甲醇水复溶(20:80, *V*:*V*)	LC–TOFMS	C_{18} (50 mm×4.6 mm, 1.8 μm)	A: 乙腈 B: 0.1%甲酸水	0.10~4.50 μg/kg	[41]

续表 3

种类	基质	方法	检测方法	液相色谱柱	流动相	LODs	参考文献
		提取与净化					
14	鱼类	乙腈提取, C_{18} 吸附	HPLC-PDA	Capcellpak C_{18} (4.6 mm×250 mm, 5 μm)	A: 0.2%乙酸水 B: 乙腈	3~6 μg/kg	[42]
13	鲤鱼	乙腈/水溶液提取(50:50, *V*:*V*)在线 MSPD 处理	on-line MSPD–LC–MS/MS	Halofused-core C_{18} silica(50 m×2.1 mm, 2.7 μm)	A: 0.1%甲酸水 B: 乙腈.	0.75~3.00 μg/kg	[43]
11	牛奶	磁性复合材料(methacrylic acid–co–ethylene glycoldimethacrylate)的 SPE 柱	LC–MS/MS	Shim-pack VP-ODS(250 mm×2 mm, 5 μm)	A: 0.2%甲酸水 B: 0.2%甲酸甲醇	0.5~49.5 ng/L	[44]
8	牛奶	乙腈(0.1%甲酸) 离心，过滤	HPLC-Q-TOF	Waters YMC ODS-AQ (2 mm×100 mm, 3 μm)	A: 乙腈 B: 0.1%甲酸水	2.5~10 μg/kg	[45]
6	牛奶，奶粉	C_{18} 搅拌吸附提取	HPLC–MS/MS	Zorbax ODS C_{18}(150 mm×2.1 mm, 3.5 μm)	A: 水 B: 甲醇	牛奶: 0.9~10.5 μg/L; 奶粉: 2.7~31.5 μg/kg	[46]
18	牛奶	酸化除蛋白, Oasis HLB SPE 柱净化	nano-LC/ESI/MS	Phenomenex Kinetex C_{18} core–shell (2.1 mm×10 cm, 2.6 μm)	A: 0.1%甲酸水 B: 乙腈	LODs: 2~40 μg/kg; LOQs: 8~96μg/kg	[47]
9	牛奶	酸化除蛋白	HPLC/MS/MS	Polar-RP80A(50 mm×2 mm, 4 μm)	A: 0.1%甲酸水 B: 0.1%甲酸乙腈	12.5~25.5 μg/kg	[48]
24	牛奶	乙腈提取，正己烷净化	UPLC-MS/MS	Acquity BEH C_{18}(100 mm×2.1 mm, 1.7 μm)	A: 0.2% 乙酸-5 mmol/L 乙酸铵水 B: 乙腈	0.04~1.35 μg/kg	[42]
4	禽蛋	Na_2EDTA 酸化乙腈 OASIS HLB cartridge	UHPLC-MS/MS	Acquity UPLC BEH C_{18} (100 mm × 2.1 mm, 1.7 μm)	A: 甲醇 B: 0.05%甲酸水	0.1~1.9 μg/kg	[50]
14	禽蛋	酸化乙腈	HPLC-MS/MS	Acquity UPLC BEH (100 mm × 2.1 mm, 1.7 μm)	A: 0.02%甲酸-1mmol/L 草酸水 B: 0.1% 甲酸乙腈	CCα: 0.5~3.8 μg/kg	[51]
3	禽蛋	酸化甲醇水(80:20, *V*:*V*) 无水 Na_2SO_4 和 NaAc，过滤	HPLC-MS/MS	C_{18} (10.0 mm×3.2 mm, 5 μm)	A: 0.1%甲酸-50%甲醇水溶液 B: 0.1%甲酸水	Method detection limits (MDL): 4.5~5.3 μg/kg	[52]
7	鸡蛋	磁力 MWCNTs 固相萃取	LC–MS/MS	Zorbax SB C_{18}(250 mm×4.6 mm, 5 μm)	A: 0.5%乙酸水 B: 甲醇	1.4~2.8 μg/kg	[53]
7	蜂蜜	McIlvaine 缓冲盐 0.1 mol/L(pH 4)，乙腈提取，以硅酸镁为载体分散的固相萃取(d-SPE)提取	UHPLC-MS/MS	Acquity UPLC™ BEH C_{18} (100 mm×2.1 mm, 1.7 μm)	A: 0.1%甲酸-5 mmol/L 甲酸铵水 B: 0.1%甲酸-5 mmol/L 甲酸铵甲醇	0.1~2.0 μg/kg	[54]

续表 3

种类	基质	方法	检测方法	液相色谱柱	流动相	LODs	参考文献
		提取与净化					
10	蜂蜜	乙腈提取	LC–MS/MS	MGIII C_{18}(150 mm×2.1 mm, 5 μm)	A: 甲醇 B: 0.3%甲酸-50 mmol/L 乙酸铵水	1.0 μg/kg	[55]
8	蜂蜜	Oasis HLB SPE 柱净化	HPLC-FLD &LC-MS/MS	Kinetex XB C_{18}(100 mm×3 mm, 2.6 μm)	A: 50 mmol/L 乙酸铵-0.3%甲酸水 B: 甲醇	0.01~0.5 μg/kg	[56]
8	蜂蜜	一种新的磺胺二甲嘧啶印迹聚合物(MIP)涂层搅拌棒	HPLC	Dikma C18 (250 mm×4.6 mm, 5 μm)	A: 1%乙腈 B: 乙酸水溶液 (2:8)	0.2 μg/L	[57]
4	蜂蜜	利用十六烷基二甲基溴化铵固定磷酸锆的 SPE 固相萃取柱	LC–MS/MS	Agilent SB C_{18}(250 mm×4.6 mm, 5 μm)	A: 0.15%甲酸水 B: 甲醇	0.25~0.5 ng/g	[58]
8	蜂蜜	磁性分子印迹 SPE 柱	LC - MS/MS	Waters Xterra C_{18}(250 mm×4.6 mm, 5 μm)	A: 0.5%乙酸水 B: 乙腈	1.5~4.3 ng/g	[59]
5	蜂蜜	空洞纤维液相膜萃取	HFRLM–LC–MS/MS	NovaPak C_{18}(150 mm×3.9 mm, 4 μm)	A: 甲醇 B: 0.1%甲酸-10 mmol/L 乙酸铵水	5.1~27.4 μg/kg	[60]
5	婴儿食品	酸化乙腈 无水 $MgSO_4$ 和 NaAc, 过滤	UHPLC-MS/MS	Acquity UPLC BEH C_{18} (100 mm×2.1 mm, 1.7 μm)	A: 0.05%甲酸水 B: 甲醇	0.2~0.5 μg/kg	[61]
16	婴儿食品	Na_2EDTA 乙腈 溶剂浓缩	UHPLC-MS/MS	Acquity HSS-T 3 (100 mm×2.1 mm, 1.8 μm)	A: 0.1%甲酸-0.5 mmol/L 乙酸铵水 B: 0.1%甲酸甲醇	LOQs: 0.1~0.5 μg/kg	[62]

更新颖的样品前处理方法是将聚甲基硅氧烷固定在磁力搅拌器上作为吸附剂, 与样品混合一定时间后, 实现磺胺类物质的有效提取。这种搅拌棒可以被再生得到重复利用。可以应用到牛奶和肉中磺胺类物质的检测。聚甲基硅氧烷固定相还能升级成分子印迹、单一聚合物集成材料或者 C_{18}。该方法是把 Fe_3O_4 用乙二醇、聚乙烯醇或油酸进行修饰, 修饰后的聚合物既具有了溶液中分子印迹结构。Fe_3O_4 与分子印迹的结合的聚合物能够在磁场下得到快速分离。新方法前处理的通式: (1)对搅拌研磨, 混合均匀的样品定量。加入吸附剂, 使待测组分被充分吸附; (2)回收吸附剂, 干燥, 将待测物从吸附机上解析并收集; (3)待仪器检测。

此外, 新方法多种吸附剂提纯单管萃取技术(single-tube extraction with multisorbent impurity trapping, STEMIT)、单管萃取多方位吸附精华法(single-tube extraction/partitioning multifunction adsorption clean-up, SEP/MAC)是 QuEChERS 方法的升级。

磺胺类药物残留的研究主要集中在肉、蛋、奶、水产品、蜂蜜和婴幼儿食品, 见表 3。从表 3 可知, 使用酸化流动相, 二级质谱检测, 检出限可达 μg/kg 级, 新技术可以将检出限减低到 ng/kg。高通量检测更集中于 UPLC 的使用; 简化提纯步骤能够有效提高回收率。在分离和净化磺胺提取液的过程中, 其疏水性下降, 提取率降低。如果提取磺胺又不改变磺胺在基质中的自然状态, 需要严格控制提取条件。磺胺类药物残留检出限的降低更多依赖于高灵敏度仪器的使用, 比如 QqTOF(quadrupole-quadrupole-orthogonal acceleration time-of-flight)和 Orbitrap(Thermo Scientific™ 公司出品的 Orbitrap 质量分析仪及其系统)。

4　检测方法

选择磺胺的检测方法基于 3 种不同的目的: 定量、验证、筛查。定量检测对灵敏度要求较高。较高灵敏度的分析仪器是定量检测的必要条件。验证试验的主要特征是为鉴别化合物特征的可靠性。前处理方法是否能够有效避免基质干扰和避免假阳性结果是验证实验的技术关键。筛查实验通常提供半定量的分析结果。如何实现快速检测、高通量检测是筛查试验的重点。理想的筛查方法应该具有很低的假阳性结果比例, 具有分析时间短、高通量、使用简单、选择性高、价格低廉等特点。

食品中的磺胺类物质的检测方法多集中在液相色谱、液质联用技术[63]。目前, 从表 3 可知, 高效液相色谱的升级是超高效液相色谱(UPLC), 提高色谱的分离速度、灵敏度和处理能力, 降低共溶物的干扰。质谱方面, 欧盟 2002/657/EC 标准规定了质谱检测模式选择的标准。HPLC-MS/MS 分析磺胺采用 ESI 正离子化模式。大多数的磺胺类物质的主碎片是 156 *m*/*z*。液质联用方法的改进是 UPLC。固定相的粒径小于 2 μm, 处理能力增加 60%。

分子荧光光度法筛查牛奶、蜂蜜中的磺胺[64]。这种方法新颖、简单、准确、高效, 1 h 能处理 50 个样品, 但需要进行衍生, 增加了实际操作检验时间成本。胶体金免疫层析法检测食品中的磺胺类药物残留[65], 方法快速节约时间成本, 但缺乏准确定量技术支撑。也有采用有免疫方法或毛细管电泳法的报道[66,67]。据报道, 磺胺的检测分析方法使用最多的是 HPLC-MS/MS, 占总分析方法的 38%, HPLC 占 22%, 电泳方法 15%[5]。

5　结论与展望

磺胺类物质检测技术的研究集中在样品制备。目前磺胺不属于违禁药品, 不允许超量使用, 这对定量检测提出更高的要求。磺胺类药物检测不仅需要仪器灵敏度达到需求, 更需要前处理技术高效。为了能够实现这 2 方面的需求, 在多种提取磺胺类药物的方法中, QuEChERS 和 SPE 2 项技术虽然是目前兼顾高通量检测目的, 适用食品范围广和相对成本较低的前处理手段, 但新技术磁力吸附载体、磁力吸附载体结合分子印迹等新技术, 为磺胺类物质的检测实现高效快速样品制备提供了更多的可能。据报道, 磁力吸附载体能够再生, 可重复性利用。如何既保证检测方法的可靠性和精确度, 又合理控制检测成本是新技术在面对实际检测工作中的问题。此外, 自动化前处理方案将是未来磺胺类药物筛查方法的重点研发内容。

检测技术上, 目前几十种磺胺类组分, 可实现高通量检测方法的建立。HPLC-MS/MS 凭借其强大的分析能力不仅是磺胺类药物, 更是很多其他药物痕量残留的主流技术手段。检测技术上的发展依赖于兼顾高通量与高精度检测的质谱检测器的发展。近几年这方面技术上的更新有 UPLC、QqTOF 和 Orbitrap。这些技术上的弊端包括仪器成本高、仪器的维护成本高、仪器配套的试剂费用高、上岗人员需要经过严格的技术培训。因此, 对于食品中磺胺类药物残留, 根据不同检测需求匹配适当的检测手段, 筛查试验后针对阳性样品采取准确定量的检测方案是目前事半功倍的检测方案。

参考文献

[1] 王綪, 金钥, 杨毅青, 等. 动物食品氟喹诺酮类药残检测国内外研究现状[J]. 食品研究与开发, 2014, (16): 121–125.
Wang J, Jin Y, Yang YQ, *et al*. The research status of fluoroquinolone residues in animal food [J]. Food Res Dev, 2014, (16): 121–125.

[2] 陈振桂, 占春瑞, 郭平, 等. 高效液相色谱法同时测定水产品中 13 种磺胺类药物残留的研究[J]. 食品科学, 2007, 28: 448–451.
Chen ZH, Zhan CR, Guo P, *et al*. A high performance liquid chromatography (HPLC) method was used to determine the residue of 13 sulfonamides in aquatic products [J]. Food Sci, 2007, 28: 448–451.

[3] 周爱霞, 苏小四, 高松, 等. 高效液相色谱测定地下水、土壤及粪便中

4 种磺胺类抗生素[J]. 分析化学, 2014, 42: 397−402.
Zhou AX, Su XS, Gao S, *et al*. High performance liquid chromatography (HPLC) was used to determine four sulfonamide antibiotics in groundwater, soil and feces [J]. Chin J Anal Chem, 2014, 42: 397−402.

[4] 李彦文, 莫测辉, 赵娜, 等. 高效液相色谱法测定水和土壤中磺胺类抗生素[J]. 分析化学, 2008, 36: 954−958.
Li YW, Mo CH, Zhao N, *et al*. High performance liquid chromatography (HPLC) was used to determine the sulfonamide antibiotics in water and soil [J]. Chin J Anal Chem, 2008, 36: 954−958.

[5] Dmitrienko SG, Kochuk EV, Apyari VV, *et al*. Recent advances in sample preparation techniques and methods of sulfonamides detection-A review [J]. Anal Chim Acta 2014, 850: 6−25.

[6] Keen PL, Montforts MHMM. Antimicrobial resistance in the environment [M]. New Jersey: John Wiley & Sons, Inc, 2011.

[7] 张元, 李伟青, 周伟娥, 等. 食品中磺胺类药物前处理及检测方法研究进展[J]. 食品科学, 2015, 36: 340−346.
Zhang Y, Li WQ, Zhou WE, *et al*. Advances in pretreatment and detection of sulfonamides in food [J]. Food Sci, 2015, 36: 340−346.

[8] 黄华, 陈君慧, 冯楠, 等. 动物源性食品中磺胺类药物残留前处理和检测方法研究进展[J]. 食品工业科技, 2013, (4): 378−381.
Huang H, Chen JH, Feng N, *et al*. Advances in the treatment and detection of sulfonamides in animal source food [J]. Sci Technol Food Ind, 2013, (4): 378−381.

[9] Sun H, Qi H, Li H. Development of capillary electrophoretic method combined with accelerated solvent extraction for simultaneous determination of residual sulfonamides and their acetylated metabolites in aquatic products [J]. Food Anal Method 2013, 6: 1049−1055.

[10] Lopes RP, Augusti DV, Souza LFD, *et al*. Development and validation (according to the 2002/657/EC regulation) of a method to quantify sulfonamides in porcine liver by fast partition at very low temperature and LC-MS/MS [J]. Anal Method, 2011, 3: 606−613.

[11] Lopes RP, Augusti DV, Oliveira AG, *et al*. Development and validation of a methodology to qualitatively screening veterinary drugs in porcine muscle via an innovative extraction/clean-up procedure and LC-MS/MS analysis [J]. Food Addit Contam A, 2011, 28: 1667−1676.

[12] Zhang Y, Xu X, Qi X, *et al*. Determination of sulfonamides in livers using matrix solid-phase dispersion extraction high-performance liquid chromatography [J]. J Sep Sci, 2012, 35: 45.

[13] Yu H, Mu H, Hu YM. Determination of fluoroquinolones, sulfonamides, and tetracyclines multiresidues simultaneously in porcine tissue by MSPD and HPLC–DAD [J]. J Pharm Anal, 2012, 2: 76−81.

[14] Aguileraluiz MM, Martínez VJL, Romerogonzález R, *et al*. Multiclass method for fast determination of veterinary drug residues in baby food by ultra-high-performance liquid chromatography–tandem mass spectrometry [J]. Food Chem, 2012, 132: 2171−2180.

[15] Lopes RP, Reyes RC, Romero-González R, *et al*. Development and validation of a multiclass method for the determination of veterinary drug residues in chicken by ultra high performance liquid chromatography–tandem mass spectrometry [J]. Talanta, 2012, 89: 201−208.

[16] Han J, Wang Y, Liu Y, *et al*. Ionic liquid-salt aqueous two-phase extraction based on salting-out coupled with high-performance liquid chromatography for the determination of sulfonamides in water and food [J]. Anal Bioanal Chem, 2013, 405: 1245−1255.

[17] Arroyo-Manzanares N, Gámiz-Gracia L, García-Campaña AM. Alternative sample treatments for the determination of sulfonamides in milk by HPLC with fluorescence detection [J]. Food Chem, 2014, 143: 459−564.

[18] Chen C, Zhang X, Long Z, *et al*. Molecularly imprinted dispersive solid-phase microextraction for determination of sulfamethazine by capillary electrophoresis [J]. Microchim Acta, 2012, 178: 293−299.

[19] Huang J, Liu J, Cong Z, *et al*. Determination of sulfonamides in food samples by membrane-protected micro-solid phase extraction coupled with high performance liquid chromatography [J]. J Chromatogr A, 2011, 1219: 66−74.

[20] Gao M, Yan H, Ning S. Water-compatible poly (hydroxyethyl methacrylate) polymer sorbent for miniaturized syringe assisted extraction of sulfonamides in milk [J]. Anal Chim Acta, 2013, 800C: 43−49.

[21] Lopes RP, Augusti DV, Oliveira AG, *et al*. Development and validation of a methodology to qualitatively screening veterinary drugs in porcine muscle via an innovative extraction/clean-up procedure and LC-MS/MS analysis [J]. Food Addit Contam A, 2011, 28: 1667−1676.

[22] Granelli K, Elgerud C, Lundström A, *et al*. Rapid multi-residue analysis of antibiotics in muscle by liquid chromatography-tandem mass spectrometry [J]. Anal Chim Acta, 2009, 637: 87−91.

[23] Li JZ. Multiclass residues screening of 105 veterinary drugs in meat, milk, and egg using ultra high performance liquid chromatography tandem quadrupole time-of-flight mass spectrometry [J]. J Liq Chromatogr R T, 2010, 34: 2286−2303.

[24] Robert C, Gillard N, Brasseur PY, *et al*. Rapid multi-residue and multi-class qualitative screening for veterinary drugs in foods of animal origin by UHPLC-MS/MS [J]. Food Addit Contam A, 2013, 30: 443−457.

[25] Zhan J, Xu DM, Wang SJ, *et al*. Comprehensive screening for multi-class veterinary drug residues and other contaminants in muscle using column-switching UPLC-MS/MS [J]. Food Addit Contam A, 2013, 30: 1888−1899.

[26] Schneider MJ, Lehotay SJ, Lightfield AR. Evaluation of a multi-class, multi-residue liquid chromatography-tandem mass spectrometry method for analysis of 120 veterinary drugs in bovine kidney [J]. Drug Test Anal, 2012, 4: 91−102.

[27] Zhao XT, Lin QB, Song H, *et al*. Development of an immunoaffinity chromatography purification and ultra performance liquid chromatography tandem mass spectrometry method for determination of 12 sulfonamides in beef and milk [J]. J Agric Food Chem, 2011, 59: 9800−9805.

[28] Stubbings G, Bigwood T. The development validation of a multiclass liquid chromatography tandem mass spectrometry (LC–MS/MS) procedure for the determination of veterinary drug residues in animal tissue using a QuEChERS (quick easy cheap effective rugged safe) approach [J] Analytica Chimica Acta, 2009, 637: 68−78.

[29] Lopes RP, Reyes RC, Romero-González R, *et al*. Development and validation of a multiclass method for the determination of veterinary drug residues in chicken by ultra high performance liquid chromatography–tandem mass spectrometry [J]. Talanta 2012, 89: 201−208.

[30] Hou XL, Wu YL, Yang T, *et al*. Multi-walled carbon nanotubes-dispersive solid-phase extraction combined with liquid chromatography-tandem mass

spectrometry for the analysis of 18 sulfonamides in pork [J]. J Chromatogr B, 2013, 929C: 107−115.

[31] Yu H, Tao Y, Chen D, *et al*. Development of a high performance liquid chromatography method and a liquid chromatography-tandem mass spectrometry method with the pressurized liquid extraction for the quantification and confirmation of sulfonamides in the foods of animal origin [J]. J Chromatogr B, 2011, 879: 2653−2662.

[32] Huang X, Chen L, Yuan D. Development of monolith-based stir bar sorptive extraction and liquid chromatography tandem mass spectrometry method for sensitive determination of ten sulfonamides in pork and chicken samples [J]. Anal Bioanal Chem, 2013, 405: 6885−6889.

[33] Xie W, Han C, Hou J, *et al*. Simultaneous determination of multiveterinary drug residues in pork meat by liquid chromatography-tandem mass spectrometry combined with solid phase extraction [J]. J Sep Sci, 2012, 35: 3447−3454.

[34] Guo B, Biology KLoC, Tr. A generic approach for expanding homolog-targeted residue screening of sulfonamides using a fast matrix separation and class- specific fragmentation-dependent acquisition with a hyb [J]. Anal Chim Acta, 2012, 737: 83−98.

[35] Dasenaki ME, Thomaidis NS. Multi-residue determination of seventeen sulfonamides and five tetracyclines in fish tissue using a multi-stage LC–ESI–MS/MS approach based on advanced mass spectrometric techniques [J]. Anal Chim Acta, 2010, 672: 93−102.

[36] Náchermestre J, Ibáñez M, Serrano R, *et al*.. Qualitative screening of undesirable compounds from feeds to fish by liquid chromatography coupled to mass spectrometry [J]. J Agric Food Chem, 2013, 61: 2077−2087.

[37] Hurtadod MJ, Maggi L, Bonetto L, *et al*. Validation of antibiotics in catfish by on-line solid phase extraction coupled to liquid chromatography tandem mass spectrometry [J]. Food Chem, 2012, 134: 1149−1155.

[38] Fedorova G, Nebesky V, Randak T, *et al*. Simultaneous determination of 32 antibiotics in aquaculture products using LC-MS/MS [J]. Chem Paper, 2014, 68: 29−36.

[39] Peters RJB, Bolck YJC, Rutgers P, *et al*. Multi-residue screening of veterinary drugs in egg, fish and meat using high-resolution liquid chromatography accurate mass time-of-flight mass spectrometry [J]. J Chromatogr A, 2009, 1216: 8206−8216.

[40] Lopes RP, Reyes RC, Romero-González R, *et a*. Multiresidue determination of veterinary drugs in aquaculture fish samples by ultra high performance liquid chromatography coupled to tandem mass spectrometry [J]. J Chromatogr B, 2012, 895−896: 39−47.

[41] Villarpulido M, Gilbertlópez B, Garcíareyes JF, *et al*. Multiclass detection and quantitation of antibiotics and veterinary drugs in shrimps by fast liquid chromatography time-of-flight mass spectrometry [J]. Talanta 2011, 85: 1419−1427.

[42] Won SY, Chang HL, Chang HS, *et al*. Monitoring of 14 sulfonamide antibiotic residues in marine products using HPLC-PDA and LC-MS/MS [J]. Food Control, 2011, 22: 1101−1107.

[43] Lu Y, Shen Q, Dai Z, *et al*. Development of an on-line matrix solid-phase dispersion/fast liquid chromatography/tandem mass spectrometry system for the rapid and simultaneous determination of 13 sulfonamides in grass carp tissues [J]. J Chromatogr A, 2011, 1218: 929−937.

[44] Gao Q, Luo D, Ding J, *et al*. Rapid magnetic solid-phase extraction based on magnetite/silica/poly(methacrylic acid-co-ethylene glycol dimethacrylate) composite microspheres for the determination of sulfonamide in milk samples [J]. J Chromatogr A, 2010, 1217: 5602−5609.

[45] Turnipseed SB, Storey JM, Clark SB, *et al*. Analysis of veterinary drugs and metabolites in milk using quadrupole time-of-flight liquid chromatography-mass spectrometry [J]. J Agric Food Chem, 2011, 59: 7569−7581.

[46] Yu C, Hu B. C_{18}-coated stir bar sorptive extraction combined with high performance liquid chromatography-electrospray tandem mass spectrometry for the analysis of sulfonamides in milk and milk powder [J]. Talanta, 2012, 90: 77−84.

[47] D'Orazio G, Rocchi S, Fanali S. Nano-liquid chromatography coupled with mass spectrometry: separation of sulfonamides employing non-porous core-shell particles [J]. J Chromatogr A, 2012, 1255: 277−285.

[48] Nebot C, Regal P, Miranda JM, *et al*. Rapid method for quantification of nine sulfonamides in bovine milk using HPLC/MS/MS and without using SPE [J]. Food Chem, 2013, 141: 2294−2299.

[49] She YX, Liu JJ, Wang J, *et al*. Determination of sulfonamides in bovine milk by ultra performance liquid chromatography combined with quadrupole mass spectrometry [J]. Anal Lett, 2010, 43: 2246−2256.

[50] Frenich AG, Aguilera-Luiz MDM, Vidal JLM, *et al*. Comparison of several extraction techniques for multiclass analysis of veterinary drugs in eggs using ultra-high pressure liquid chromatography–tandem mass spectrometry [J]. Anal Chim Acta, 2010, 661: 150−160.

[51] Jiménez V, Rubies A, Centrich F. Development and validation of a multiclass method for the analysis of antibiotic residues in eggs by liquid chromatography-tandem mass spectrometry [J]. J Chromatogr A, 2011, 1218: 1443−1451.

[52] Capriotti AL, Cavaliere C, Piovesana S, *et al*.. Corrigendum to “Multiclass screening method based on solvent extraction and liquid chromatography–tandem mass spectrometry for the determination of antimicrobials and mycotoxins in egg” [J]. J Chromatogr A, 2012, 1268: 84−90.

[53] Yang X, Jie D, Chen H, *et al*. Fast determination of sulfonamides from egg samples using magnetic multiwalled carbon nanotubes as adsorbents followed by liquid chromatography-tandem mass spectrometry [J]. Food Chem, 2013, 140: 83−90.

[54] Orso D, Floriano L, Ribeiro LC, *et al*. Simultaneous determination of multiclass pesticides and antibiotics in honey samples based on ultra-high performance liquid chromatography-tandem mass spectrometry [J]. Food Anal Method, 2016, 9: 1638−1653.

[55] Tian W, Gao L, Zhao Y, *et al*. Simultaneous determination of metronidazole, chloramphenicol and 10 sulfonamide residues in honey by LC–MS/MS [J]. Anal Method, 2013, 5: 1283−1288.

[56] Tölgyesi Á, Berky R, Békési K, *et al*. Analysis of sulfonamide residues in real honey samples using liquid chromatography with fluorescence and tandem mass spectrometry detection [J]. J Liq Chromatogr R T, 2012, 36: 1105−1125.

[57] Xu Z, Song C, Hu Y, *et al*. Molecularly imprinted stir bar sorptive extraction coupled with high performance liquid chromatography for trace analysis of sulfa drugs in complex samples [J]. Talanta 2011, 85: 97−103.

[58] Hou J, Yan J, Zhang F, *et al*. Evaluation of intercalated α-zirconium phosphate as sorbent in separation and detection of sulfonamides in honey

[J]. Food Chem, 2014, 150: 58–64.

[59] Chen L, Zhang X, Sun L, *et al*. Fast and selective extraction of sulfonamides from honey based on magnetic molecularly imprinted polymer [J]. J Agric Food Chem, 2009, 57: 10073–10080.

[60] Bedendo GC, Carasek E. A simple hollow fiber renewal liquid membrane extraction method for analysis of sulfonamides in honey samples with determination by liquid chromatography–tandem mass spectrometry[J]. J Chromatogr A, 2010, 1217(42): 6449–6454.

[61] Aguilera-Luiz MM, Vidal JLM, Romero-González R, *et al*. Multiclass method for fast determination of veterinary drug residues in baby food by ultra-high-performance liquid chromatography–tandem mass spectrometry [J]. Food Chem, 2012, 132: 2171–2180.

[62] Zhan J, Zhong YY, Yu XJ, *et al*. Multi-class method for determination of veterinary drug residues and other contaminants in infant formula by ultra performance liquid chromatography–tandem mass spectrometry [J]. Food Chem, 2013, 138: 827–287.

[63] 刘兴泉, 冯震, 姚蕾, 等. 采用高通量微生物法和 HPLC 法检测猪肉中四环素和磺胺类抗生素残留[J]. 食品与发酵工业, 2011, 37: 194–197.
Liu XQ, Feng Z, Yao L, *et al*. The determination of tetracycline and sulfa antibiotic residues in pork by high-throughput microbiological method and HPLC method were used [J]. Food Ferment Ind, 2011, 37: 194–197.

[64] Llorent MEJ. Monitoring of sulfonamides by a multicommutation flow-analysis assembly: use of quenching effect on terbium luminescence [J]. Anal Lett, 2009, 43: 2283–2295.

[65] 韩静, 刘恩梅, 王帅, 等. 胶体金免疫层析法检测食品中的磺胺类药物残留[J]. 现代食品科技, 2011, 27: 603–606.
Han J, Liu EM, Wang S, *et al*. The colloidal gold immunochromatography was used to detect the residues of sulfonamides in food [J]. Mod Food Sci Technol, 2011, 27: 603–606.

[66] 曹喜春, 许杨, 何庆华, 等. 同时检测动物样品中四种磺胺药物残留的膜基质免疫分析法[J]. 食品工业科技, 2015, 36: 65–69.
Cao XC, Xu Y, He QH, *et al*. The membrane matrix immunoassay was used to detect the residue of four sulfonamides in animal samples [J]. Sci Technol Food Ind, 2015, 36: 65–69.

[67] 郝晓丽, 谷学新, 叶能胜, 等. 毛细管电泳法检测肉类中 5 种磺胺类药物残留研究[J]. 药物分析杂志, 2009, (4): 579–581.
Hao XL, Gu XX, Ye NS, *et al*. A capillary electrophoresis method was used to detect the residue of 5 sulfonamides in meat [J]. J Pharm Anal, 2009, (4): 579–581.

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