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Multi-class Method for the Determination of Anthelmintic and Antiprotozoal Drugs in Livestock Products by Ultra-High-Performance Liquid Chromatography–Tandem Mass Spectrometry

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Abstract

The objective of this study was to establish a multi-residue quantitative method for the analysis of anthelmintic and antiprotozoal drugs in various livestock products (beef, pork, and chicken) using the ultra-high-performance liquid chromatography–tandem mass spectrometry (UHPLC-MS/MS). Each compound performed validation at three different levels i.e., 0.5, 1, and 2× the maximum residue limit (MRL) according to the CODEX guidelines (CAC/GL 71-2009). This study was conducted according to the modified quick, easy, cheap, effective, rugged, and safe (QuEChERS) procedure. The matrix-matched calibrations gave correlation coefficients >0.98, and the obtained recoveries were in the range of 60.2–119.9%, with coefficients of variation ≤32.0%. Furthermore, the detection and quantification limits of the method were in the ranges of 0.03–3.2 and 0.1–9.7 μg kg^{-1}, respectively. Moreover, a survey of residual anthelmintic and antiprotozoal drugs was also carried out for in 30 samples of beef, pork, and chicken collected in Korea. Toltrazuril sulfone was detected in all three samples. Thus,

our results indicated that the developed method is suitable for determining the anthelmintic and antiprotozoal drug contents in livestock products.

Keywords: Anthelmintic, Antiprotozoal, Livestock products, UHPLC-MS/MS, Multi-class analysis, Veterinary drugs

Introduction

With the consumption of livestock products increasing annually, veterinary drugs are being increasingly employed to promote growth and prevent and treat disease (Zeleny et al., 2006). If these drugs or their metabolites are not fully excreted, consuming the derived animal products can lead to potential health risks for the consumers. To address this issue, the residual tolerance standards of such compounds are strictly regulated (Tufa 2015). Generally, such residues are generated because of excessive use or noncompliance with the withdrawal period (Danaher et al., 2007; Delatour et al., 1981; Whittaker et al., 1992). Veterinary medicines include antibiotics, synthetic antibacterial agents, nervous system drugs, hormones, anticoccidial drugs, antimicrobial agents, and anthelmintics (Rana et al., 2019). Despite their advantages, antibiotics have been reported to lead to the generation and propagation of resistant bacteria, in addition to the induction of hypersensitivity reactions, tumor induction, abnormal physical development, and teratogenesis (Abbas et al., 2011; González-Díaz et al., 2005). Thus, maximum residue limits (MRLs) have been set for 193 substances in Korea, including 26 banned substances. For example, the number of MRLs of the anthelmintic and antiprotozoal drugs are 26 and 23, respectively (Ministry of Food and Drug Safety of Korea, 2023).

As one example drug class, the anthelmintic drugs are used to treat parasites (Danaher et al., 2007). More specifically, the benzimidazoles (e.g., albendazole, cambendazole,

carbendazim, febantel, flubendazole, oxfendazole, oxibendazole, mebendazole, thiabendazole, and triclabendazole) are widely used in agriculture (Cano et al., 1987). In addition, avermectin is a macrocyclic lactone anthelmintic agent produced by Streptomyces abermitiles. To broaden its therapeutic range, the original structure of avermectin has been modified by substitution to give abamectin, ivermectin, doramectin, and eprinomectin. In this group of compounds, abamectin is used as an insecticide, and its side effects include psychosis, respiratory failure, and hypotension (Wang et al., 2009). In addition, ivermectin is a hydrogenated version of abamectin that is effective in treating onchocerciasis, despite causing various side effects, such as a rash, swelling, headache, and dizziness (Hoyos et al., 2016).

In contrast, antiprotozoal drugs are used to treat protozoan infections. In particular, coccidiostats are used to prevent or treat coccidiosis, which is a disease caused by protozoan parasites that parasitize and attack the digestive tract of animals, causing diarrhea and secondary infections such as enteritis (Roila et al., 2019; Rusko et al., 2019).

According to previous studies, anthelmintic and antiprotozoal drugs frequently exceed the MRL. For example, Lee et al. (2017) confirmed MRL violations in pigs treated with mebendazole, while Escribano et al. (2012) confirmed an excess of ivermectin in the liver and milk of cattle, sheep, pigs, and rabbits. Moreover, Cooper et al. (2012) reported that the MRLs of rafoxanide and doramectin were violated in pigs. Thus, the development of novel methods with high sensitivities and resolutions is required due to the frequent occurrences of anthelmintic and antiprotozoal drugs in animal samples. In this paper shows sensitivity excellent compared to other studies (Clarke et al., 2013; Kang et al., 2014; Kang et al., 2015). To ensure domestic food safety in Korea, The Ministry of Food and Drug Safety is preparing to introduce a positive list system (PLS).

The PLS Program for veterinary drugs covers livestock and fishery products produced in 2024 or beyond. Previously, the CODEX guidelines (CAC/GL 71-2009) were applied in cases where no MRL had been previously established in Korea; alternatively, the lowest MRL established for similar products was employed. However, with the introduction of the PLS, a limit of 10 μg kg^{-1} is applied if a Korean MRL is unavailable. Therefore, a rapid, highly sensitive, and reliable analytic method is required to prepare for the introduction of the PLS. Among the various analytical techniques reported to date, ultra-high-performance liquid chromatography–tandem mass spectrometry (UHPLC-MS/MS) has become a popular technique for analyzing the veterinary drugs owing to its ability to analyze a wide range of compounds at low levels quickly (Moloney et al., 2012). In addition, according to recent study trends, the quick, easy, cheap, effective, rugged, and safe (QuEChERS) method has been used to develop multi-residue analytical approaches for analyzing pesticides and veterinary drugs in various matrices. The QuEChERS approach is flexible and can be modified depending on the matrix and the properties of the analyte. This method is beneficial because it minimizes the time required to complete the extraction and cleanup processes, while also reducing the cost of analysis (Chen et al., 2021; Kang et al., 2014; Stubbings et al., 2009; Ye et al., 2022).

Thus, by applying a modified QuEChERS approach, this study aims to increase the extraction efficiency by adding anhydrous magnesium sulfate ($MgSO_4$) and sodium chloride (NaCl) to remove moisture and interfering substances from the sample. This is followed by the separation of the extraction solution and the aqueous layer using the salting-out method. Furthermore, during the dispersive solid-phase extraction (d-SPE) step, $MgSO_4$, primary secondary amine (PSA), and C_{18} are used for matrix cleanup. Consequently, this study aims to verify the sensitivity and quantitation of 54

anthelmintic and antiprotozoal drugs that are commonly present in livestock products, and this will be achieved using a modified QuEChERS extraction and purification approach, followed by UHPLC-MS/MS analysis.

Materials and Methods

Chemicals and reagents

The following standards were purchased from Sigma-Aldrich (St. Louis, MO, USA; Steinheim, Germany): 5-hydroxy thiabendazole, albendazole sulfoxide, bithionol, carbendazim, fluazuron, keto triclabendazole, isometamidium, ternidazole, thiophanate, and toltrazuril sulfone. Arprinocide, benznidazole, diethylcarbamazine, and halofuginone were purchased from Toronto Research Chemicals (Toronto, Canada). Emamectin b_{1a} (emamectin) and ornidazole were purchased from ChemService (West Chester, PA, USA) and StordSynthesis (Hebei Province, China), respectively. The rest of 42 compounds (abamectin, albendazole, albendazole sulfone, etc.) were purchased from Dr. Ehrenstorfer (Augsburg, Germany). Methanol (MeOH) and acetonitrile (MeCN) were purchased from Merck, Inc. (Darmstadt, Germany). Dimethyl sulfoxide (DMSO), formic acid, $MgSO_4$, and NaCl were purchased from Sigma-Aldrich (St. Louis, MO, USA), and PSA was purchased from Agilent Technologies (Santa Clara, CA, USA). Ammonium formate was purchased from Alfa Aesar (Ward Hill, MA, USA) and C_{18} (55–105 μm, 125 Å) was purchased from Waters (Milford, MA, USA). A syringe filter from Teknokroma (Barcelona, Spain) was used by incorporating it into polytetrafluoroethylene (PTFE) membrane filters (0.2 μm). For albendazole, albendazole sulfone, albendazole sulfoxide, buquinolate, flubendazole, oxfendazole, oxfendazole sulfone, oxibendazole, mebendazole, mebendazole amine, standard solutions (1000 μg mL^{-1}) were prepared in MeOH/DMSO (1:1, v/v). Similarly, MeCN

was used as the solvent to prepare a standard stock solution of guaifenesin (1000 μg mL^{-1}), while DMSO was used to prepare the stock solutions for fenbendazole, 5-hydroxy mebendazole, methylbenzoquate, and nicarbazin (1000 μg mL^{-1}). The corresponding standard stock solutions (1000 μg mL^{-1}) were prepared at MeOH in all other compounds. All standard stock solutions were stored in amber bottles at −20℃.

Sample collection and preparation

Beef (n= 10), pork (n= 10), and chicken (n= 10) were purchased from local markets in Korea. Each sample was homogenized and stored in a freezer (−20°C) until required for further use. Thus, each homogenized sample (2 g) was weighed into a 50 mL centrifuge tube and then extracted to using 0.1% formic acid in MeCN/MeOH (95:5, v/v, 10 mL) and water (10 mL) under shaking for 5 min. Subsequently, $MgSO_4$ (4 g) and NaCl (1 g, original QuEChERS salt) were added to the sample. After, shaken for 5 min, and subjected to centrifugation at 4700 *g* (4℃, 10 min). The supernatant was then transferred to a 50 mL centrifuge tube containing C_{18} (150 mg), PSA (150 mg), and $MgSO_4$ (900 mg). And then, obtained mixture was shaken for 5 min and centrifuged at 4700 *g* (4℃, 5 min). The obtained supernatant (5 mL) was transferred to a new centrifuge tube, DMSO (20 μL) was added, and the solvent was evaporated under a stream of N_2 at 40℃. Afterwards, the residue was dissolved in a mixture of MeOH and water (1:1, v/v, 1 mL), and the extract was subsequently filtered through a 0.2 μm PTFE filter before analysis. (Kim et al., 2021).

UHPLC-MS/MS conditions

Separation was conducted on a Shimadzu UHPLCMS 8060 triple quadrupole mass spectrometer (MS, Shimadzu, Kyoto, Japan) equipped with a Waters X-SELECT HSS

C_{18} column (2.1 mm × 150 mm, 3.5 μm particle size, Waters, Dublin, Ireland). Data processing used LC solution software version (5.99) form Shimadzu. Gradient separation was performed using a binary gradient composed of water containing 0.1% formic acid and 2 mM ammonium formate (mobile phase A) and MeCN containing 0.1% formic acid (mobile phase B). The gradient profile was as follows: 0 min, 15% B; 2 min, 15% B; 12.5 min, 95% B; 17.0 min, 95% B; 17.1 min, 15% B; 20.0 min, 15% B. The injection volume was 5 μL, and a flow rate of 0.3 mL/min was used under argon gas. The MS source settings were as follows: capillary voltages = 4.0 kV (positive) and 2.8 kV (negative); capillary temperature = 350℃, auto-sampler temperature = 15℃, column temperature = 40℃, and cone voltage = 30 kV. The MS instrument was operated in the electrospray ionization (ESI) mode with positive and negative switching modes, and scheduled multiple reaction monitoring (MRM) was employed for all target compounds.

Method validation

The linearity, accuracy, precision, limit of detection (LOD), and limit of quantification (LOQ) of the developed method were determined according to the CODEX guidelines (CAC/GL71-2009) and the Ministry of Food and Drug Safety (MFDS) of Korea guidelines (MFDS, 2016). More specifically, the accuracy and precision were determined by analyzing negative samples at three different concentrations, i.e., spiking at 0.5, 1, and 2× the MRL. In addition, the analysis included the determination of toltrazuril (toltrazuril sulfone), emamectin (emamectin B1a), and nicarbazin (N,N'-bis(4-nitrophenylurea)), based on the specified marker residues. The matrix-matched standards for the calibration curves were prepared using a six-point range of target concentrations (i.e., 0.25, 0.5, 1, 2, 4, and 8× the MRL). The LODs and LOQs were

238 defined as the concentrations at which the signal-to-noise (S/N) ratios were ≥3 and ≥10,
239 respectively.
240
241 **Matrix effect**
242 To determine the degree of the matrix effect for each system, the matrix-matched curve
243 of a post-extraction spiked sample and the solvent standard curve were compared at the
244 same concentration (in the case set MRL value; 0.25, 0.5, 1, 2, 4, and 8× the MRL and
245 in the case not set MRL value; 2.5, 5, 10, 20 and 40 µg kg-1), as outlined in Equation
246 (1) below. In general, the matrix components of a sample can either increase or decrease
247 ionization efficiency due to interfering substances, i.e. salts, lipids, and peptides
248 (Antignac et al., 2005).

$$\mathrm{ME}(\%) = \left(\frac{Slope_{matrix\ matched\ standard\ curve}}{Slope_{solvent\ standard\ curve}} - 1\right) \times 100 \quad (1)$$

249
250
251 **Results and Discussion**
252 **UHPLC-MS/MS optimization**
253 The MS parameters were determined using individual standard solutions and were
254 optimized based on the mass spectra of all compounds. Using the ESI mode with
255 positive and negative switching and MRM, bithionol, chlorfluazuron, oxyclozanide,
256 keto triclabendazole, nicarbazine, niclosamide, and toltrazuril sulfone were detected as
257 their corresponding $[M-H]^-$ species, semduramyicin was detected as $[M+NH]^+$, and all
258 other compounds were detected as $[M+H]^+$ mode. Using standard solutions diluted in
259 MeOH/water (1:1, v/v), the MS parameters were optimized using a cone voltage of 30
260 V. The parent and daughter ions were selected by optimizing the collision energy.
261 Furthermore, daughter ions with higher intensities and better peak shapes were selected

as quantitative ions. Most compounds possessed one parent ion and either one or two daughter ions. The optimized precursor ions, daughter ion collision energies, and retention times of all compounds are listed in Table 1. A reversed-phase X-SELECT HSS C_{18} column was used to separate the various veterinary drugs examined herein. This column was selected because multi-residue analysis was previously performed using a C_{18} column (Dasenaki et al., 2015). It was found that mobile phase A improved sensitivity and reduced peak tailing (Chang et al., 2019; Clarke et al., 2013; Frenich et al., 2014), while mobile phase B produced a better peak shape than a mixture of MeOH and 0.1% formic acid in MeCN (Zrncic et al., 2014). Figure S1 shows the extracted ion chromatograms of the target compounds. These chromatograms were observed by injecting an aliquot (5 μL) of the desired standard solution into the beef sample at a concentration of 100 μg kg^{-1} (fenbantel and isometamidium) or 10 μg kg^{-1}, which corresponds to spiking of 1× the MRL.

Sample preparation

This study was conducted according to the modified QuEChERS procedure. The sample extraction and clean-up conditions were optimized based on a previously used method for multiclass drug analysis (Kim et al., 2021). Kim et al. used a modified QuEChERS type extraction method and added the concentration step. The original QuEChERS method consists of two steps an extraction/partitioning step with the addition of salts, and a clean-up step that uses d-SPE. More specifically, sample extraction was carried out using 0.1% formic acid with MeCN/MeOH (95:5, v/v), which had been previously demonstrated to yield a high recovery rate (Clarke et al., 2013; Lopes et al., 2012). In addition, $MgSO_4$ was employed due to its good water absorbency properties, which permits salting-out, while NaCl was added to increase the polarity of the extraction

287 solvent and enhance the extraction selectivity (Rejczak & Tuzimski et al., 2015). For
288 sample clean-up, PSA was used to remove fatty acids and organic acids, $MgSO_4$ was
289 used to remove water, and a C_{18} absorbent was used to remove non-polar components
290 (Anastassiades et al., 2003; Wilkowska et al., 2011). DMSO was added prior to sample
291 concentration to enhance the sample recovery to act as a keeper during evaporation
292 (Kim et al., 2021; Whelan et al., 2010).
293
294 **Validation of the analytical method**
295 Method validation was performed in terms of the linearity, accuracy, precision, LOD,
296 and LOQ. All compounds exhibited a best linearity, with correlation coefficients (r^2)
297 exceeding 0.98 at matrix-matched calibration at six points. The accuracy, expressed as
298 the recovery, ranged from 60.2 to 119.9%, and the coefficients of variation (CV) ranged
299 from 1.2 to 31.5% for the three determined levels. In the chicken samples, the average
300 recovery of 2-amino albendazole sulfone was ~111.1%, which was considered
301 unacceptable based on the recovery limit of 110% specified by the CODEX guidelines
302 at a concentration of 200 μg kg^{-1}; all other compounds satisfied the CODEX guidelines.
303 In addition, inter-laboratory (n=2) validation was conducted according to CODEX
304 guidelines (CAC/GL-71) and the results was satisfied with the guideline. Table 2 lists
305 the accuracies and precisions obtained of all compounds following their analyses in the
306 three matrices. In addition, the LOD values ranged from 0.3 to 3 μg kg^{-1}, while the
307 LOQ values ranged from 1 to 10 μg kg^{-1}, which are lower than the corresponding
308 values of the Korean MRLs. It should be noted that, in general, the LOQ values were ~1
309 μg kg^{-1}; however, the corresponding values for imidocarb and pyrantel in beef were 10
310 μg kg^{-1}, respectively, while oxfendazole had an LOQ value of 10 μg kg^{-1}. The LOD,
311 LOQ, and Korean MRL values for the three matrices (beef, pork, and chicken) are given

in Table 3, wherein it can be deduced that the obtained values were satisfactory. Thus, the developed method appeared to demonstrate an acceptable analytical performance for residue control in livestock products.

Matrix effects

The matrix effects observed for the various samples and compounds are presented in Figure 1 and Table 4. Figure 1 shown that the positive and negative matrix effects were observed for the livestock products examined herein. These effects were classified into five groups, namely high signal suppression (ME < −50%), moderate suppression (ME < −10 to −50%), no matrix effect (ME > −10 to <10%), moderate signal enhancement (ME > 10 to <50%), and high signal enhancement (ME > 50%) (Chatterjee et al., 2016). It was found that the matrix effects varied in the range of −95–56%, wherein high matrix effects were observed for 11 compounds (20.0%) in the beef matrix, nine compounds (16.4%) in the pork matrix, and seven compounds (12.7%) in the chicken matrix. No matrix effect was observed for 9 compounds (16.4%) in beef samples, 17 compounds (30.9%) in the pork samples, and 15 compounds (27.3%) in the chicken samples. In addition, moderate matrix effects were observed for 35 compounds (63.6%) in the beef matrix, 29 compounds (52.7%) in the pork matrix, and 33 compounds (60.0%) in the chicken matrix. Most compounds (beef; 47 pork; 40, chicken;47) exhibited signal suppression, while a few (beef; 6, pork; 14, chicken;7) exhibited signal enhancement. Pyrantel is neither in both suppression and signal enhancement in beef. The beef and chicken matrices were largely responsible for signal suppression, while the pork matrix led to both signal suppression and enhancement. The greatest suppression and enhancement were observed for the pork matrix, and these corresponded to −95 and 56% for isometamidium and halofuginone, respectively. These

variable matrix effects are likely due to the complexity of the tissue matrix. Although the most effective means to compensate for matrix effects is to use an internal standard (Yin et al., 2016), internal standards are expensive, and the corresponding compounds for the various target compounds are often unavailable. Thus, the current study was performed using a matrix-matched standard curve.

Application of our method to real samples

To demonstrate the applicability of our method, the livestock samples (n = 30) collected from Korean local markets were analyzed. Among these samples, toltrazuril sulfone was detected in pork and chicken samples at concentrations of 1 μg kg^{-1} in pork (2 samples) and 5 μg kg^{-1} in chicken (1 sample); however, it should be noted that their concentrations were lower than the Korean MRL (Table 3). Toltrazuril is a triazine-based antiprotozoal that is commonly used in pigs and chicken turkeys (Mehlhorn et al., 1988). Although toltrazuril sulfone is reportedly more effective in smaller amounts than toltrazuril, it is highly toxic and can cause side effects if consumed by humans through the food chain (Lindsay et al., 2000; Franklin et al., 2003).

In a previous study, toltrazuril and toltrazuril sulfone were detected in frankfurter sausages at a concentration of 2 μg kg^{-1} (Martínez-Villalba et al., 2010). Indeed, the detection of anthelmintic and antiprotozoal drugs in livestock samples has been widely reported (Adesiyun et al., 2021; Pawar et al., 2021; Yoo et al., 2021). Ai et al. (2011) detected diclazuril in rabbit muscles (n = 10), while monensin (1.4–22 ng g^{-1}, n = 42) and ractopamine (0.6–64 ng g^{-1}, n = 15) were detected in bovine liver, and monensin (0.8 and 1.1 ng g^{-1}, n = 2) and ractopamine (1.8–6.3 ng g^{-1}, n = 12) were detected in bovine muscle. Ractopamine (0.5–67 ng g^{-1}, n = 7) was detected in bovine kidney, while monensin (2.0 ng g^{-1}, n = 1), decoquinate (150 ng g^{-1}, n = 1), lasalocid (1.5 and

14 ng g^{-1}, *n* = 2), narasin (4 ng g^{-1}, n = 1), and *N*,*N*′-bis(4-nitrophenylurea (190 ng g^{-1}, *n* = 1) were detected in chicken muscle (Matus et al., 2016). Furthermore, according to Kang et al. (2015), acetyl salicylic acid (12–576 µg kg^{-1}; *n* = 28, 50–53 µg kg^{-1}; n = 1) was detected in pigs and chickens, paracetamol (28–381 µg kg^{-1}, *n* = 15) was detected in pigs, clopidol (9–4614 µg kg^{-1}) was detected in chickens (*n* = 28) and ducks (*n* = 6), while diclazuril and amprolium were detected in chicken livers (104–525 µg kg^{-1}, *n* = 8; and 195-196 µg kg^{-1}, *n* = 2, respectively). Moreover, toltrazuril and its metabolites (toltrazuril sulphone and toltrazuril sulfoxide) were detected in chicken liver (*n* = 29) at concentrations of 161–469, 67–1822, and 209–760 µg kg^{-1}, respectively, while phenylbutazone and its metabolite (oxyphenylbutazone) were detected at levels of 247 and 15 µg kg^{-1} in cattle liver (*n* = 1), respectively, and nicarbazin was detected at a concentration of 0.05 µg kg^{-1} in eggs (*n* = 1) (Kang et al., 2015).

Overall, this study shows that the detection amount is smaller than in previous studies (Ai et al., 2011; Matus et al., 2016). Therefore, monitoring results shows that livestock products are a safe level of residues. Therefore, the UHPLC-MS/MS method established in this study can be used as a reliable method for the detection of anthelmintic and antiprotozoal drug residues.

Conclusions

We herein reported the validation of an analytical method for the simultaneous quantification of anthelmintic and antiprotozoal drugs in livestock products (i.e., beef, pork, and chicken). This method exhibited an overall satisfactory performance in terms of its accuracy and precision, thereby indicating its applicability as a quantitative method. In addition, the current method achieved low limits of quantitation (0.1–9.7 µg kg^{-1}) for all target compounds in the beef, pork, and chicken. Following the successful analysis of 30 real samples obtained from markets in Korea, three samples gave

detection rate of 10%; however, the residual concentrations did not exceed those of the Korean maximum residue limits. Thus, the obtained the results confirm the suitability of this method for the detection of anthelmintic and antiprotozoal drugs in livestock products. Further study needs to increase the number of real samples and have to perform a risk assessment for the detected results. In addition, previous studies show the detection of residues in by-products (Kang et al., 2015). Therefore, it is necessary to conduct extended experiments on by-products. Nevertheless, the proposed method can be used to successfully perform the routine analysis of residues in livestock products, thereby significantly contributing to the development of multi-residue analysis and safety management in the future. Also, we expect to use the developed method to prepare for PLS program for veterinary drug in livestock and fishery products produced in 2024.

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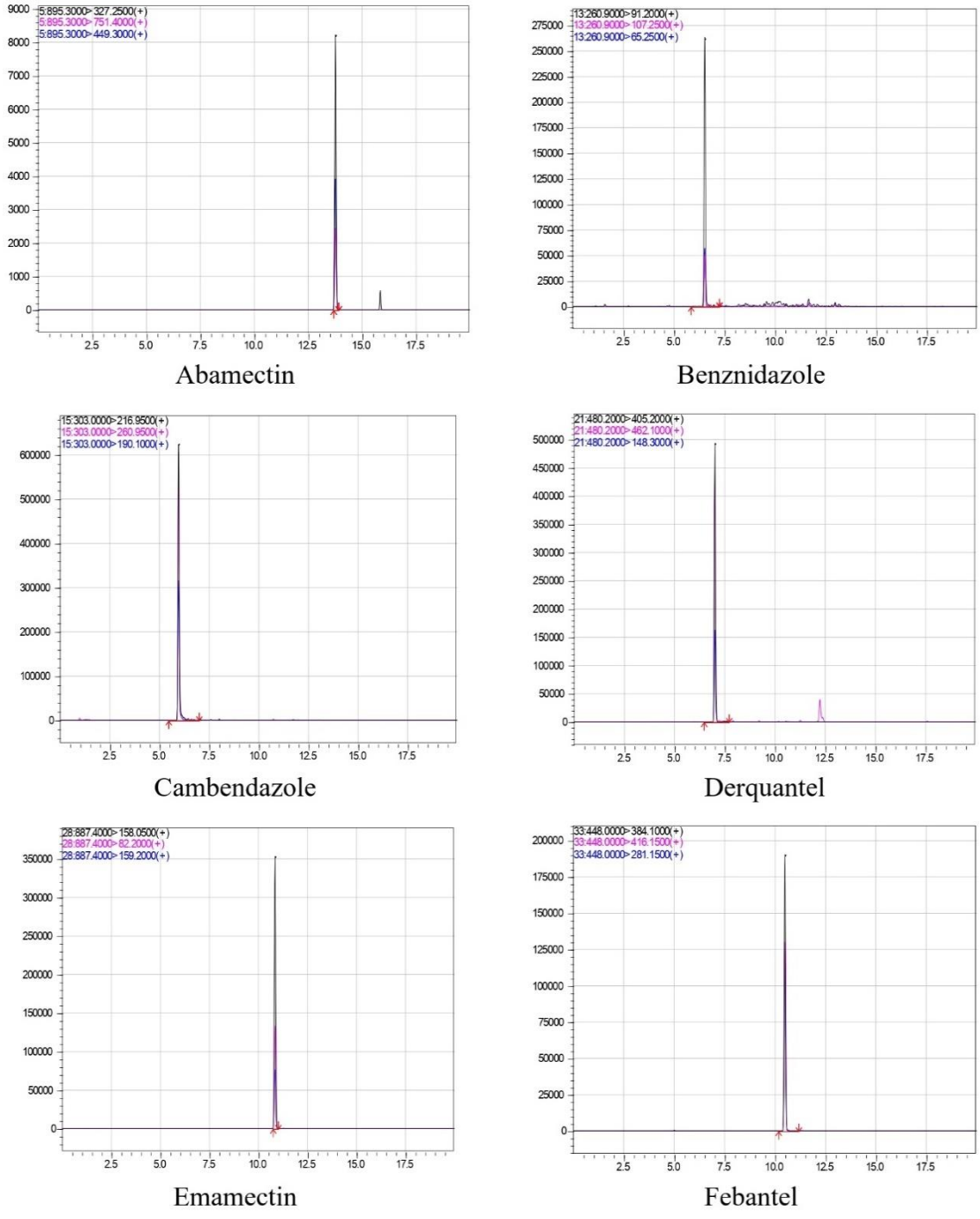
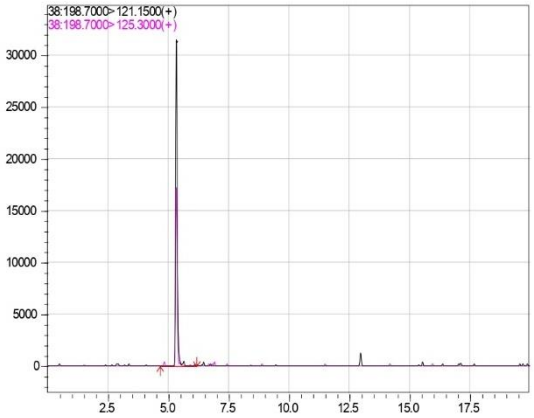
Figure S1. UHPLC–MS/MS representative chromatograms of the target compounds in beef (febantel and isomatamidium = 100 µg kg^{-1}; other compounds = 10 µg kg^{-1}; black = quantification ions; red and blue = qualification ions).

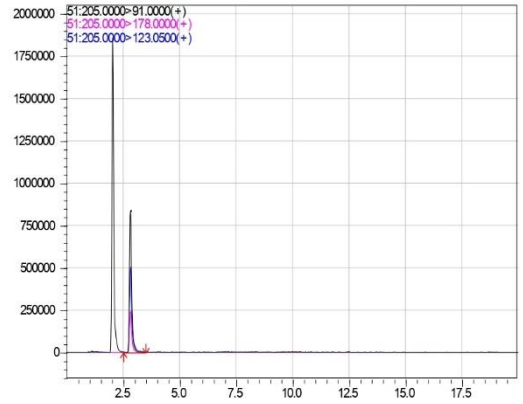




Guaifenesin

Halofuginone

Isometamidium



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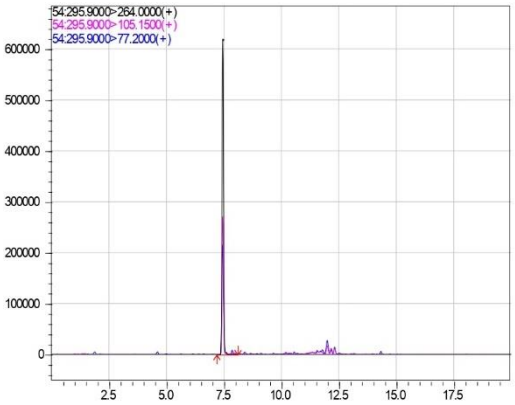

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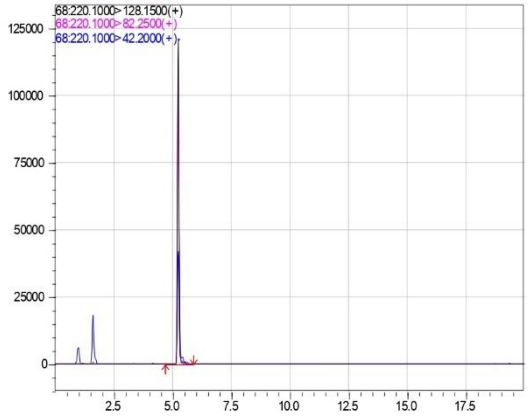
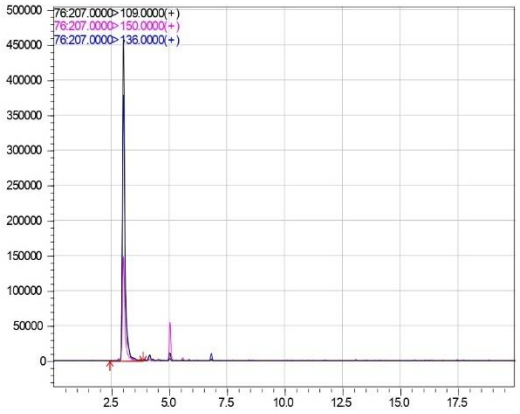


Ornidazole

571



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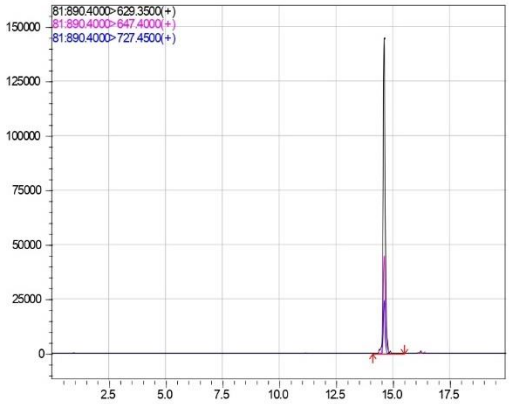
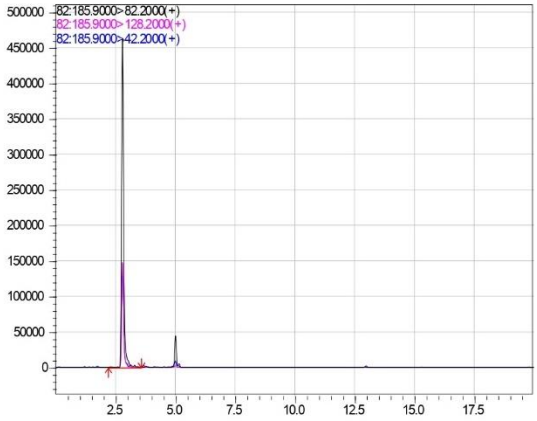


Semduramicin



Ternidazole

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Figure 1. Sample matrix effects of the target compounds in the beef, pork, and chicken matrices.

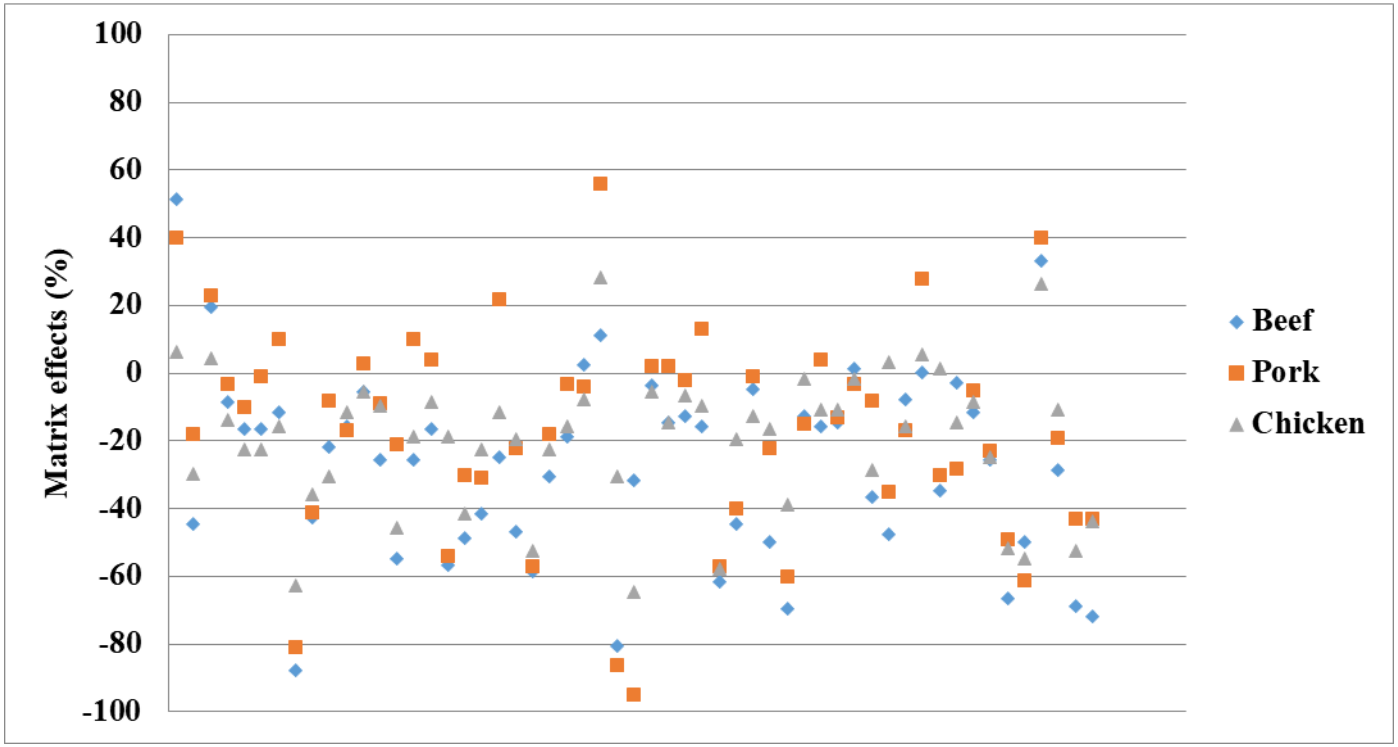

Table 1. UHPLC-MS/MS parameters of the 54 target compounds

Class	Compounds	ESI (+/−)	Molecular weight (*m/z*)	Precursor ion (*m/z*)	[a]Product ion (*m/z*)	Collision Energy (eV)	Retention time (min)
Anthelmintic	Abamectin	+	872.5	895.0	**327.3**	20	13.8
					449.3	20	
					751.4	20	
	Albendazole	+	265.1	266.0	**234.0**	20	8.00
					191.1	20	
					159.2	20	
	Albendazole sulfoxide	+	281.1	282.0	**208.1**	16	5.12
					240.1	19	
					159.2	19	
	Albendazole sulfone	+	297.1	298.0	**159.2**	20	6.19
					224.1	20	
					266.1	20	
	2-Amino albendazole sulfone	+	239.1	240.0	**133.2**	17	2.84
					198.2	16	
					105.2	30	
	Benznidazole	+	260.1	261.0	**91.2**	20	6.51
					107.3	18	
					65.3	17	
	Bithionol	−	353.9	352.0	**161.1**	−25	12.43
					192.0	−25	
					125.1	−42	
	Cambendazole	+	302.1	303.0	**217.0**	20	6.15
					261.0	20	
					190.1	24	
	Carbendazim	+	191.1	192.0	**132.2**	20	2.78
					105.2	30	
					160.1	30	
	Carnidazole	+	244.1	245.0	**118.2**	30	6.51
					75.2	14	

				47.2	26	
				518.0	−15	
Chlorfluazuron	−	539.0	538.0	355.0	−22	13.1
				175.1	−42	
				171.2	15	
Cymiazole	+	218.1	219	144.1	20	6.00
				77.3	23	
				405.2	20	
Derquantel	+	479.6	481	462.1	20	7.10
				148.3	30	
				100.0	20	
Diethylcarbamazine	+	199.2	200.0	72.0	20	1.79
				44.2	20	
				158.1	30	
Emamectin	+	885.5	886.0	82.2	34	10.98
				159.2	32	
				384.1	19	
Febantel	+	446.1	448.0	416.2	14	10.50
				281.2	33	
				268.0	20	
Fenbendazole	+	299.1	299.9	159.0	35	8.90
				131.3	46	
				158.2	22	
Fluazuron	+	505.0	506.0	141.2	49	12.50
				351.1	21	
				282.1	21	
Flubendazole	+	313.1	314.0	123.2	35	7.90
				95.2	50	
				123.2	34	
2-Amino flubendazole	+	255.1	256.0	95.2	34	6.00
				123.2	17	
				91.0	20	
Levamisole	+	204.1	205.0	123.1	20	2.91

				178.0	20	
				264.0	20	
Mebendazole	+	295.1	295.9	105.2	30	7.55
				77.2	20	
				105.2	16	
Mebendazole amine	+	237.1	238.0	133.3	30	5.71
				77.2	16	
				266.0	20	
5-Hydroxy mebendazole	+	297.1	298.0	79.2	20	5.88
				160.2	20	
				123.0	20	
Morantel	+	220.1	221.0	164.0	20	5.58
				111.0	21	
				171.1	−20	
Niclosamide	−	326.0	325.0	289.0	−18	11.22
				135.1	−21	
				128.2	10	
Ornidazole	+	219.0	220.0	82.3	20	5.29
				42.2	10	
				91.1	20	
Oxantel	+	216.1	217.0	118.3	20	3.08
				131.3	29	
				159.2	19	
Oxfendazole	+	315.1	316.0	284.2	21	6.23
				191.2	21	
				300.1	19	
Oxfendazole sulfone	+	331.1	332.0	159.2	12	7.23
				131.3	12	
				176.0	20	
Oxibendazole	+	249.1	250.0	218.0	20	6.57
				148.2	18	
Oxyclozanide	−	398.9	397.0	**362.0**	−19	11.08
				202.0	−24	

					176.2	−27	
					159.0	20	
	Praziquantel	+	312.2	313.0	131.3	21	8.97
					174.2	19	
					109.0	20	
	Pyrantel	+	206.1	207.0	150.0	34	4.25
					136.0	34	
					82.2	30	
	Ternidazole	+	185.1	186.0	128.2	12	2.87
					42.2	12	
					178.0	20	
	Tetramisole	+	204.1	205.0	91.0	20	2.91
					123.1	20	
					121.2	19	
	Thiabendazole	+	201.0	202.0	175.0	20	3.20
					131.0	20	
	5-Hydroxy thiabendazole	+	217.0	218.0	65.2	26	1.92
					191.1	16	
					147.2	16	
	Thiophanate	+	370.1	371.0	81.3	15	9.11
					151.0	20	
					273.9	35	
	Triclabendazole	+	358.0	359.0	343.9	30	10.99
					171.1	53	
					182.1	−25	
	Keto triclabendazole	−	328.0	326.9	146.1	−34	9.63
					118.0	−40	
					142.9	20	
Antiprotozoal	Arprinocid	+	277.1	278.0	107.2	16	6.01
					108.2	19	
	Buquinolate	+	361.2	362.0	**204.0**	20	10.05
					316.1	21	

				148.2	25	
				123.1	20	
Diaveridine	+	260.1	261.0	81.3	20	2.84
				245.0	19	
				121.2	15	
Guaifenesin	+	198.1	199.0	125.3	25	5.30
				100.2	29	
Halofuginone	+	413.0	415.8	120.2	20	6.19
				138.3	20	
				188.2	20	
Imidocarb	+	348.2	349.0	162.2	13	1.54
				97.7	24	
				299.2	10	
Isometamidium	+	460.2	461.0	313.2	16	5.70
				314.3	30	
Methylbenzoquate, Nequinate	+	365.2	366.0	**334.1**	20	9.88
				91.0	22	
				201.1	26	
				675.4	24	
Monensin	+	692.4	693.0	461.4	24	16.60
				479.3	24	
				136.9	−20	
Nicarbazine	−	302.1	301.0	107.1	−30	9.74
				46.0	−20	
				629.4	34	
Semduramicin	+	872.5	890.0	647.4	20	14.49
				727.5	34	
				121.2	19	
Tinidazole	+	247.1	248.0	82.2	11	4.30
				128.2	11	
Toltrazuril sulfone	−	457.1	456.0	**41.8**	−22	9.96
				399.1	−22	

[a] The bold underlined text indicates the quantification ions.

Table 2. Validation of the analytical method for the 54 target compounds (n = 5)

Compound	Beef				Pork				Chicken			
	Target concentration levels (µg kg^{-1})	[A]Rec. (%)	[A] CV (%)	r^2	Target concentration levels (µg kg^{-1})	[A]Rec. (%)	[A] CV (%)	r^2	Target concentration levels (µg kg^{-1})	[A]Rec. (%)	[A] CV (%)	r^2
Abamectin	5	97.3	27.9	0.9914	5	75.6	25.6	0.9865	5	94.1	22.8	0.9838
	10	102.0	19.1		10	73.2	24.3		10	105.7	16.4	
	20	91.8	19.5		20	98.1	17.7		20	105.1	11.6	
Albendazole	50	77.6	12.2	0.9990	50	90.3	7.9	0.9970	50	107.8	9.1	0.9952
	100	73.8	12.3		100	97.0	9.0		100	111.2	11.7	
	200	93.2	6.4		200	94.6	11.5		200	109.0	12.6	
Albendazole sulfone	50	109.4	13.4	0.9946	50	107.0	16.3	0.9944	50	109.0	5.9	0.9987
	100	110.8	20.1		100	91.0	18.6		100	107.3	8.6	
	200	98.8	10.4		200	94.0	11.9		200	93.6	13.6	
Albendazole sulfoxide	50	96.3	9.2	0.9985	50	85.5	11.2	0.9996	50	110.1	10.6	0.9996
	100	92.2	10.0		100	93.8	8.3		100	110.0	9.1	
	200	85.9	3.9		200	93.3	1.2		200	107.2	4.3	
2-Amino albendazole sulfone	50	106	4.8	0.9979	50	100.1	3.6	0.9999	50	113.8	7.2	0.9998
	100	100.8	7.5		100	100.5	9.7		100	111.7	5.8	
	200	85.7	18.0		200	99.7	2.8		200	111.1	7.0	
Arprinocid	5	106.6	4.7	0.9974	5	92.0	5.2	0.9996	5	105.3	5.4	0.9984
	10	87.4	8.2		10	98.3	5.1		10	111.6	3.0	
	20	88.9	6.6		20	90.5	6.6		20	109.3	5.7	
Benznidazole	5	92.7	5.9	0.9969	5	98.5	5.2	0.9991	5	116.0	8.9	0.9996
	10	92.4	7.8		10	96.5	5.6		10	115.9	6.2	
	20	92.8	6.4		20	93.2	6.0		20	112.0	6.5	

	5	71.0	6.4		5	79.4	21.0		5	104.2	16.1	
Bithionol	10	76.9	14.9	0.9983	10	90.3	11.4	0.9966	10	116.9	18.0	0.9854
	20	98.5	13.0		20	112.4	17.5		20	115.0	18.2	
	5	93.5	16.2		5	90.6	12.5		5	90.8	7.9	
Buquinolate	10	97.6	10.4	0.9922	10	83.5	23.0	0.9960	10	107.9	4.2	0.9987
	20	100.6	11.1		20	82.6	11.7		20	81.9	10.1	
	5	99.8	10.3		5	60.9	28.5		5	105.9	16.2	
Cambendazole	10	74.1	16.7	0.9944	10	100.4	8.1	0.9944	10	115.4	9.8	0.9914
	20	86.4	7.2		20	102.9	9.9		20	114.3	11.5	
	5	107.2	10.5		5	75.3	14.7		5	110.8	8.3	
Carbendazim	10	119.9	11.0	0.9995	10	100.4	7.4	0.9976	10	102.4	11.8	0.9995
	20	104.8	8.0		20	102.5	10.9		20	101.9	6.0	
	5	99.8	9.2		5	96.4	8.2		5	101.6	8.9	
Carnidazole	10	93.4	11.3	0.9990	10	103.0	4.8	0.9995	10	99.3	2.8	0.9998
	20	98.4	11.7		20	92.0	7.2		20	99.5	9.0	
	5	103.5	11.1		5	118.6	11.9		5	101.2	8.6	
Chlorfluazuron	10	89.7	25.0	0.9946	10	81.6	6.3	0.9944	10	103.5	19.0	0.9962
	20	89.5	14.2		20	75.7	19.5		20	75.6	7.3	
	5	66.7	9.1		5	73.6	4.0		5	90.9	9.5	
Cymiazole	10	71.6	7.3	0.9972	10	83.8	12.4	0.9875	10	79.0	23.4	0.9948
	20	84.5	7.9		20	75.8	15.3		20	85.7	21.9	
	5	102.7	11.0		5	107.0	3.2		5	105.1	9.4	
Derquantel	10	80.6	9.6	0.9963	10	84.0	7.1	0.9996	10	104.0	5.0	0.9991
	20	76.5	13.8		20	75.8	8.9		20	101.4	10.3	
	5	113.3	5.8		5	98.8	9.7		5	99.4	3.8	
Diaveridine	10	103.0	9.6	0.9993	10	100.7	4.5	0.9987	10	110.7	3.2	0.9944
	20	101.2	12.8		20	95.2	8.0		20	109.9	2.0	
	5	94.5	5.8		5	94.5	13.1		5	94.4	20.7	
Diethylcarbamazine	10	96.3	12.0	0.9988	10	103.0	5.5	0.9993	10	95.5	12.0	0.9992
	20	86.3	5.3		20	88.7	12.5		20	82.1	21.7	

	5	93.3	3.0		5	68.9	10.1		5	104.5	13.1	
Emamectin	10	101.5	13.8	0.9971	10	74.8	11.3	0.9843	10	95.7	7.8	0.9985
	20	106.6	5.6		20	86.0	13.6		20	84.2	18.9	
	50	87.3	11.3		50	87.8	4.9		50	93.4	17.5	
Febantel	100	76.6	8.2	0.9945	100	88.2	9.4	0.9982	100	93.7	2.5	0.9987
	200	74.9	8.9		200	77.5	5.6		200	92.2	8.8	
	50	73.6	14.3		50	91.7	13.9		50	107.3	8.2	
Fenbendazole	100	84.3	16.7	0.9955	100	96.6	27.7	0.9926	100	107.5	6.9	0.9955
	200	109.9	5.2		200	93.6	17.3		200	103.4	17.5	
	100	116.5	7.2		5	97.7	30.7		5	94.2	15.0	
Fluazuron	200	108.2	13.8	0.9888	10	78.6	19.2	0.9592	10	112.7	15.3	0.9839
	400	103.7	6.1		20	109.6	12.0		20	84.5	19.9	
	5	100.2	8.0		5	94.8	19.6		5	110.9	13.6	
Flubendazole	10	82.8	6.2	0.9973	10	88.5	8.1	0.9978	10	98.6	10.6	0.9987
	20	78.1	6.7		20	70.4	14.7		20	88.5	12.0	
	5	79.7	10.4		5	93.9	9.4		5	107.5	7.7	
2-Amino flubendazole	10	87.4	20.8	0.9944	10	99.5	7.6	0.9985	10	102.4	9.9	0.9972
	20	99.3	9.2		20	94.7	12.8		20	101.5	6.4	
	5	111.1	29.5		5	80.9	25.3		5	82.9	20.8	
Guaifenesin	10	102.9	20.3	0.9936	10	86.0	20.0	0.9884	10	103.3	16.2	0.9961
	20	101.8	13.1		20	83.7	13.9		20	108.6	15.1	
	5	84.9	13.6		5	118.4	7.2		5	113.2	8.6	
Halofuginone	10	90.3	13.5	0.9976	10	89.6	10.5	0.9973	10	97.2	6.9	0.9990
	20	81.4	6.5		20	71.4	4.0		20	95.3	15.3	
	150	99.2	11.9		5	104.6	11.0		5	103.9	17.0	
Imidocarb	300	88.8	15.6	0.9844	10	106.0	9.0	0.9983	10	103.4	17.3	0.9916
	600	91.5	9.2		20	97.5	15.5		20	80.4	16.1	
	50	114.5	7.7		5	91.5	16.2		5	83.4	12.1	
Isometamidium	100	106.5	14.8	0.9987	10	74.2	19.6	0.9883	10	65.5	8.4	0.9974
	200	95.4	9.5		20	76.4	19.0		20	78.4	18.1	

	5	111.8	2.2		5	102.4	5.6		5	95.3	12.0	
Levamisole	10	104.3	7.5	0.9978	10	90.2	12.1	0.9994	10	98.1	3.6	0.9994
	20	88.8	8.9		20	90.1	10.5		20	94.8	10.0	
	5	91.5	5.0		30	91.3	5.4		30	114.2	9.7	
Mebendazole	10	78.7	11.6	0.9995	60	97.1	9.9	0.9981	60	111.3	3.8	0.9995
	20	100.4	7.3		120	90.5	6.3		120	103.6	6.9	
	5	94.4	10.6		30	84.3	8.0		30	115.5	10.0	
Mebendazole amine	10	110.9	5.0	0.9802	60	84.5	5.4	0.9994	60	107.2	10.7	0.9993
	20	104.0	12.3		120	85.1	6.4		120	97.8	7.4	
	5	93.8	5.8		30	95.5	8.0		30	100.3	8.3	
5-Hydroxy mebendazole	10	84.6	8.3	0.9993	60	89.0	7.1	0.9991	60	103.8	6.8	0.9962
	20	78.5	19.2		120	83.1	4.8		120	102.6	4.9	
	5	78.1	6.6		5	99.9	14.7		5	88.8	11.5	
Methylbenzoquate	10	81.6	22.4	0.9860	10	89.0	15.6	0.9911	10	117.6	20.9	0.9942
	20	99.9	14.2		20	85.8	12.4		20	89.2	11.8	
	25	73.5	7.1		25	84.3	9.9		25	110.9	15.1	
Monensin	50	78.6	10.5	0.9966	50	86.4	13.9	0.9945	50	93.3	15.9	0.9916
	100	90.2	15.9		100	86.3	20.0		100	102.1	10.9	
	5	114.7	6.6		5	81.9	10.6		5	96.1	7.1	
Morantel	10	87.0	19.3	0.9985	10	87.1	16.4	0.9983	10	99.7	6.2	0.9960
	20	83.8	9.8		20	90.0	5.3		20	94.1	7.5	
	5	77.3	3.0		5	66.5	7.5		5	106.1	7.4	
Nicarbazin	10	77.6	9.3	0.9936	10	74.4	15.0	0.9876	10	106.9	6.7	0.9999
	20	90.6	10.2		20	83.6	12.2		20	98.6	9.6	
	5	107.1	11.2		5	75.7	8.4		5	106.3	19.9	
Niclosamide	10	87.8	25.8	0.9853	10	87.8	31.5	0.9899	10	98.7	15.2	0.9988
	20	84.1	13.9		20	93.2	18.4		20	106.0	20.5	
	5	89.4	13.4		5	78.2	26.6		5	91.2	16.7	
Ornidazole	10	79.6	15.0	0.9994	10	108.6	9.0	0.9958	10	101.9	11.0	0.9912
	20	89.5	11.0		20	106.3	10.1		20	105.0	14.4	

	5	93.4	4.7		5	98.2	4.2		5	99.5	6.0	
Oxantel	10	91.9	7.0	0.9999	10	99.2	2.0	0.9997	10	107.3	1.8	0.9982
	20	94.2	7.4		20	95.8	3.3		20	107.2	2.2	
	50	110.1	8.1		50	87.9	9.3		50	99.8	7.6	
Oxfendazole	100	106.7	4.5	0.9998	100	102.7	7.8	0.9989	100	99.3	8.3	0.9974
	200	105.1	8.0		200	105.9	4.7		200	96.3	5.9	
	50	99.3	2.3		50	111.8	12.7		50	104.3	6.9	
Oxfendazole sulfone	100	96.3	4.0	0.9979	100	100.1	9.1	0.9992	100	102.7	9.4	0.9994
	200	103.8	5.1		200	101.6	7.8		200	100.8	6.1	
	50	93.6	8.5		50	84.6	9.1		50	113.9	11.3	
Oxibendazole	100	86.6	10.4	0.9942	100	88.0	6.3	0.9977	100	110.3	2.6	0.9994
	200	92.3	8.8		200	85.6	10.4		200	106.8	6.6	
	5	104.8	10.4		5	93.0	9.4		5	104.0	13.7	
Oxyclozanide	10	91.8	3.7	0.9970	10	98.2	14.2	0.9940	10	111.6	6.5	0.9959
	20	94.1	5.3		20	104.3	12.8		20	113.5	11.1	
	5	104.0	9.9		5	91.8	9.4		5	98.9	5.3	
Praziquantel	10	86.4	17.9	0.9992	10	110.4	12.3	0.9993	10	114.1	11.2	0.9953
	20	90.6	7.6		20	114.3	8.6		20	116.1	8.2	
	5	97.6	8.8		5	111.8	9.1		5	114.3	15.0	
Pyrantel	10	100.5	4.7	0.9989	10	98.0	5.9	0.9953	10	112.7	6.3	0.9995
	20	97.3	12.3		20	88.3	9.3		20	95.1	15.1	
	5	76.7	22.0		5	80.8	25.6		5	110.0	15.3	
Semduramicin	10	79.1	20.6	0.9930	10	95.7	24.7	0.9957	10	85.7	13.0	0.9974
	20	96.5	21.7		20	112.4	10.5		20	94.5	14.8	
	5	92.4	29.6		5	91.4	22.9		5	102.7	15.4	
Ternidazole	10	107.0	9.1	0.9807	10	107.9	8.5	0.9947	10	112.1	8.2	0.9843
	20	84.6	20.7		20	80.9	14.9		20	108.1	6.0	
	5	100.1	4.5		5	90.8	3.1		5	105.0	2.1	
Tetramisole	10	100.3	5.5	0.9997	10	97.4	4.1	0.9992	10	100.5	4.5	0.9999
	20	98.8	5.7		20	95.4	2.9		20	102.0	2.0	

	5	101.6	7.6		5	78.7	15.1		5	101.4	10.4	
Thiabendazole	10	103.3	3.0	0.9998	10	110.3	5.1	0.9966	10	119.9	4.0	0.9970
	20	106.6	5.5		20	114.2	7.4		20	116.8	7.8	
	5	110.9	18.3		5	93.1	14.4		5	116.7	18.0	
5-Hydroxy thiabendazole	10	90.7	11.4	0.9931	10	116.9	7.2	0.9950	10	105.6	18.7	0.9946
	20	76.4	9.9		20	111.8	7.9		20	72.0	17.7	
	5	117.4	9.3		5	84.1	10.0		5	109.9	15.8	
Thiophanate	10	84.1	16.2	0.9908	10	103.9	20.9	0.9974	10	92.4	4.2	0.9941
	20	90.2	4.2		20	93.4	4.8		20	94.3	10.9	
	5	78.7	10.6		5	96.3	12.0		5	94.6	17.1	
Tinidazole	10	103.3	9.0	0.9889	10	93.0	9.3	0.9997	10	86.2	9.6	0.9985
	20	100.9	9.3		20	73.7	9.2		20	92.5	6.9	
	50	98.3	8.1		50	86.0	11.8		50	111.5	7.0	
Toltrazuril sulfone	100	95.0	9.5	0.9954	100	101.4	7.5	0.9996	100	108.3	3.4	0.9992
	200	101.1	10.2		200	104.3	3.8		200	103.9	7.6	
	100	85.3	15.5		5	86.8	13.1		5	110.5	7.8	
Triclabendazole	200	92.4	8.1	0.9832	10	83.0	15.5	0.9983	10	109.5	12.3	0.9970
	400	107.1	12.2		20	82.6	19.7		20	104.8	6.6	
	100	82.5	7.4		5	91.2	8.1		5	104.6	25.2	
Keto triclabendazole	200	87.7	11.0	0.9929	10	90.2	15.9	0.9899	10	107.7	11.5	0.9951
	400	92.2	7.9		20	83.7	16.1		20	96.1	13.9	

[A] Rec.: Recovery; CV: coefficient validation.

Table 3. The LODs, LOQs (μg kg^{-1}) and Korean MRLs (μg kg^{-1}) for livestock products

Compounds	Beef			Pork			Chicken		
	[A]MRL (μg kg^{-1})	LOD (μg kg^{-1})	LOQ (μg kg^{-1})	[A]MRL (μg kg^{-1})	LOD (μg kg^{-1})	LOQ (μg kg^{-1})	[A]MRL (μg kg^{-1})	LOD (μg kg^{-1})	LOQ (μg kg^{-1})
Abamectin	10	0.03	0.1	10	0.1	0.3		0.03	0.1
Albendazole	100	0.03	0.1	100	0.03	0.1	100	0.03	0.1
Albendazole sulfone	100	0.1	0.3	100	0.1	0.3	100	0.1	0.3
Albendazole sulfoxide	100	0.2	0.6	100	0.3	1	100	0.2	0.7
2-Amino albendazole sulfone	100	0.1	0.2	100	0.1	0.4	100	0.1	0.4
Arprinocid		0.03	0.1		0.03	0.1		0.03	0.1
Benznidazole		0.2	0.7		0.2	0.5		0.2	0.6
Bithionol	10	0.3	1		0.3	0.9		0.1	0.2
Buquinolate		0.03	0.1		0.03	0.1		0.03	0.1
Cambendazole		0.1	0.2		0.1	0.2		0.1	0.2
Carbendazim		0.03	0.1	10	0.1	0.2		0.03	0.1
Carnidazole		0.03	0.1		0.03	0.1		0.03	0.1
Chlorfluazuron		0.1	0.2		0.03	0.1		0.03	0.1
Cymiazole		0.03	0.1		0.03	0.1		0.03	0.1
Derquantel		0.1	0.4		0.1	0.3		0.1	0.2
Diaveridine		0.03	0.1		0.03	0.1	50	0.1	0.3
Diethylcarbamazine	10	0.2	0.5		0.2	0.5		0.1	0.4
Emamectin		0.03	0.1		0.03	0.1		0.03	0.1
Febantel	100	0.03	0.1	100	0.03	0.1	50	0.03	0.1
Fenbendazole	100	0.1	0.3	100	0.1	0.2	50	0.1	0.2
Fluazuron	200	0.2	0.5		0.03	0.1		0.03	0.1
Flubendazole		0.03	0.1	10	0.03	0.1	200	0.03	0.1

2-Amino flubendazole		0.03	0.1	10	0.1	0.3	200	0.1	0.2
Guaifenesin	10	0.8	2.4	10	1.3	3.8	10	1	3
Halofuginone		0.03	0.1		0.03	0.1		0.03	0.1
Imidocarb	300	0.5	1.5		0.03	0.1		0.5	1.5
Isometamidium	100	0.1	0.2		0.03	0.1		0.03	0.1
Levamisole	10	0.03	0.1	10	0.03	0.1	10	0.03	0.1
Mebendazole		0.03	0.1	60	0.03	0.1	60	0.03	0.1
Mebendazole amine		0.1	0.3	60	0.1	0.4	60	0.2	0.6
5-Hydroxy mebendazole		0.2	0.5	60	0.1	0.3	60	0.2	0.5
Methylbenzoquate		0.03	0.1		0.03	0.1	10	0.03	0.1
Monensin	50	0.03	0.1	50	0.03	0.1	50	0.03	0.1
Morantel		0.9	2.6		0.9	2.7		1.1	3.4
Nicarbazin		0.1	0.2		0.03	0.1	200	0.1	0.2
Niclosamide		0.2	0.5		0.1	0.3		0.1	0.2
Ornidazole		0.1	0.2		0.1	0.4		0.2	0.5
Oxantel		0.2	0.5		0.2	0.5		0.2	0.5
Oxfendazole	100	0.03	0.1	100	0.03	0.1	50	0.03	0.1
Oxfendazole sulfone	100	0.03	0.1	100	0.03	0.1	50	0.03	0.1
Oxibendazole	100	0.03	0.1	100	0.03	0.1		0.0	0.1
Oxyclozanide		0.2	0.7		0.2	0.5		0.1	0.4
Praziquantel		0.03	0.1		0.03	0.1		0.0	0.1
Pyrantel		3.2	9.7		0.2	0.5		0.2	0.6
Semduramicin		0.03	0.1		0.03	0.1	100	0.3	1
Ternidazole		0.1	0.2		0.1	0.3		0.1	0.3
Tetramisole	10	0.03	0.1	10	0.03	0.1	10	0.0	0.1
Thiabendazole	10	0.03	0.1	10	0.03	0.1		0.03	0.1

5-Hydroxy thiabendazole	10	0.1	0.2	10	0.03	0.1		0.03	0.1
Thiophanate		0.03	0.1	10	0.03	0.1		0.03	0.1
Tinidazole		0.03	0.1		0.1	0.2		0.03	0.1
Toltrazuril sulfone	100	0.1	0.3	100	0.03	0.1	100	0.03	0.1
Triclabendazole	200	0.03	0.1		0.03	0.1		0.03	0.1
Keto triclabendazole	200	0.3	0.9		0.1	0.2		0.1	0.2

[A] MRL: Maximum residue limit; no MRL values were set for the blanks.

Table 4. Matrix effects of the 54 target compounds

No.	Compound	Beef	Pork	Chicken
1	Abamectin	51	40	6
2	Albendazole	−45	−18	−30
3	Albendazole sulfone	19	23	4
4	Albendazole sulfoxide	−9	−3	−14
5	2-Amino albendazole sulfone	−17	−10	−23
6	Arprinocid	−17	−1	−23
7	Benznidazole	−12	10	−16
8	Bithionol	−88	−81	−63
9	Buquinolate	−43	−41	−36
10	Cambendazole	−22	−8	−31
11	Carbendazim	−16	−17	−12
12	Carnidazole	−6	3	−6
13	Chlorfluazuron	−26	−9	−10
14	Cymiazole	−55	−21	−46
15	Derquantel	−26	10	−19
16	Diaveridine	−17	4	−9
17	Diethylcarbamazine	−49	−30	−42
18	Emamectin	−42	−31	−23
19	Febantel	−25	22	−12
20	Fenbendazole	−47	−22	−20
21	Fluazuron	−59	−57	−53
22	Flubendazole	−31	−18	−23
23	2-Amino flubendazole	−19	−3	−16
24	Guaifenesin	2	−4	−8
25	Halofuginone	11	56	28
26	Imidocarb	−81	−86	−31
27	Isometamidium	−32	−95	−65
28	Levamisole	−4	2	−6
29	Mebendazole	−15	2	−15
30	Mebendazole amine	−13	−2	−7
31	5-Hydroxy mebendazole	−16	13	−10

32	Methylbenzoquate	−62	−57	−58
33	Monensin	−45	−40	−20
34	Morantel	−5	−1	−13
35	Nicarbazin	−50	−22	−17
36	Niclosamide	−70	−60	−39
37	Ornidazole	−13	−15	−2
38	Oxantel	−16	4	−11
39	Oxfendazole	−15	−13	−11
40	Oxfendazole sulfone	1	−3	−2
41	Oxibendazole	−37	−8	−29
42	Oxyclozanide	−48	−35	3
43	Praziquantel	−8	−17	−16
44	Pyrantel	0	28	5
45	Semduramicin	−35	−30	1
46	Ternidazole	−3	−28	−15
47	Tetramisole	−12	−5	−9
48	Thiabendazole	−26	−23	−25
49	5-Hydroxy thiabendazole	−67	−49	−52
50	Thiophanate	−50	−61	−55
51	Tinidazole	33	40	26
52	Toltrazuril sulfone	−29	−19	−11
53	Triclabendazole	−69	−43	−53
54	Keto triclabendazole	−72	−43	−44