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Residue Monitoring Analysis of Veterinary Drugs and Environmental Contaminants in Exporting Livestock Products to Korea

Su Min Nam[1], Su Jin Pyo[2], Hyoung Joon Moon[1], Hwan Goo Kang[1]*, Sung Hee Choi[2]*

[1]*Department of Animal Health and Welfare, Semyung University, Jecheon, Korea*
[2]*Department of Food Intelligence Information research, CHEM. I. NET. Co., Ltd, Seoul, Korea*

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ABSTRACT - This study analyzed veterinary drugs that violated the maximum residue limit by type of livestock product and country, based on the National Residues Program (NRP) data submitted by countries exporting livestock products to South Korea in 2022 and 2023. The top residue violations included 241 cases of neomycin, 183 of penicillin G, 151 of gentamicin, 113 of ceftiofur, and 103 of nicarbazin. Beef has the highest number of residue violations with 1,056 cases, followed by 245 of pork, 106 of poultry meat, 389 of milk, and 103 of eggs. In beef, antibiotics are used to treat infectious diseases, and antipyretics and veterinary drugs such as penicillin G, ceftiofur, flunixin, neomycin, benzylpenicillin, meloxicam, florfenicol, and zilpaterol for growth promotion. Ractopamine is used to promote bacterial growth in pork. Doxycycline, chloramphenicol, benzylpenicillin, nandrolone, thiouracil, and streptomycin are the most commonly found substances, along with hormones used to promote pregnancy. The level of nicarbazin, an antibiotic used to treat coccidiosis, was most frequently violated in poultry meat, followed by streptomycin, aminoglycoside, benzylpenicillin, doxycycline, and other antibiotics. Although veterinary drug residue violations have been reported in many countries, residues of environmental contaminants, such as dioxins and polychlorinated biphenyls (PCBs) have also been reported in European countries. The differences in residue levels in each country are likely due to differences in livestock raised and managed. The high levels of residue in beef are likely due to cows being treated more individually than other animals. The present study provides a scientific and practical basis for the annual national residue inspection program for imported livestock products by highlighting the substances each country should control, and during the process of inspecting veterinary drugs in imported livestock products in Korea.

Key words: Imported meat, National residue program, Maximum residue limit, Veterinary drugs

Livestock can be intentionally or unintentionally exposed to veterinary drugs, pesticides, and environmental contaminants during the raising process, which can be residual in livestock products consumed by humans, causing public health problems. Each country has a National Residue Program (NRP) to determine the residues of these substances in a certain percentage of the livestock produced. This program determines the maximum amount that can be residual in these livestock products, i.e., the maximum residue level (MRL, mg/kg).

*Correspondence to: Sung Hee Choi, Department of Food Intelligence Information research, CHEM.I.NET. Co.,Ltd, Seoul 07964, Korea
Tel: +82-70-5056-2880, Fax: +82-2-2647-4932
E-mail: shchoi@cheminet.kr
*Co-correspondence to: Hwan Goo Kang, Department of Animal Health and Welfare, Semyung University, Jecheon 27136, Korea
Tel: +82-43-649-1699, Fax: +82-43-649-1758
E-mail: toxfree@gmail.com

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The substances and values of MRLs in livestock products are set and operated somewhat differently by each country and livestock product. In the case of undetectable substances (or prohibited substances) in food, Korea has 26 substances[1)], the United States has 14 substances (prohibited for extra label use in food-producing animals)[2)], the European Union has 10 substances (prohibited substances in food-producing animals)[3)], Australia has 10 substances (not permitted for use on food-producing animals) and Japan listed 24 substances as undetectable substances in food[4,5)]. Codex also suggested 12 substances that no MRL recommended due to specific human health[6)].

In Korea, the NRP reported a violation rate of 0.25-0.35% for the four years from 2017-2020[7)], while the EU reported a rate of 0.30-0.35% (2017-2019) and the US reported 0.38-0.49% (2016-2019), similar to Korea's results. In Korea, aminoglycoside antibiotics were the most violated, while Europe had the highest detection of anabolic, undetectable substances in food and antimicrobials, and the United States had the highest detection of ceftiofur[8,9)].

In Korea, Article 7 of the import permitted countries (regions) and import hygiene conditions for livestock products or food originating from animals requires exporting countries that export livestock products to Korea to operate a residue management program for controlling residues (inspection institutions, annual inspection plans, inspection methods, inspection results, etc.) and providing the residue surveillance data annually[10].

This study was conducted to analyze the main violations of substances in livestock products by country and by livestock product based on the results of the NRP submitted in 2023 and 2024 from countries exporting livestock products to Korea.

Materials and Methods

In this study, the results of the national residue inspection programs submitted in 2022 and 2023 from countries that export livestock products to Korea were provided to the Ministry of Food and Drug Safety (MFDS). Substances that violated the MRLs were determined based on the residue allowance standards set by the exporting country.

To analyze residues in livestock products (beef, pork, poultry meat, milk, and eggs), we selected countries with 10 or more cases of residue violations based on the results of NRPs conducted by countries exporting livestock products to Korea from 2019 to 2022.

Results

Number of violations of veterinary drug and environmental contaminants for maximum residue limits by livestock products

NRP results submitted by countries exporting livestock products to Korea showed a total of 3,887 residue violations, with the highest number of violations in beef (2,991), followed by pork (333) and poultry meat (143). In milk and eggs, there were 261 and 159 cases, respectively. In 2021, the number of violations was high at 1,809, showing a slight increase from year to year. In Country C1 and C3, the highest number of residue violations was in milk and eggs, but in all other countries, the highest number of residue violations was in beef (Table 1, 2).

Classification of veterinary drugs and environmental contaminants violated of maximum residue limit in major livestock products according to their usage

The violated substances were classified according to their intended use: antimicrobials, non-detectable substances, anticoccidials, non-steroidal anti-inflammatory drugs, antiparasitics, heavy metals, growth promoters, anabolic steroids, antipyretic analgesics, bronchodilators, hormones, glucocorticoids, etc. (Table 3).

When categorized using veterinary drugs that violated the MRL in major livestock products, antimicrobials, non-

Table 1. Violation numbers of veterinary drugs and environmental contaminants in livestock products from major countries from 2019 to 2022

Year	Beef	Poultry meat	Pork	Milk	Egg	Sum
2019	164	17	57	65	62	365
2020	527	21	54	76	49	727
2021	1,809	25	42	60	24	1,960
2022	491	80	180	60	24	835
Sum	2,991	143	333	261	159	3,887

* Data originated from the NRP results of the corresponding countries submitted by livestock exporters in 2022 and 2023.

Table 2. Violation of veterinary drugs and environmental contaminants in livestock products from major countries

Category	Countries																	
	A1	A2	B1	C1	C3	C5	E	G1	I1	I2	M	N1	O	S1	S2	S3	T3	U2
Beef	13	177	22	24	67	47	1,296	46	2	20	49	59	33	19				1,030
Poultry meat			4		49	2						4			10			17
Pork	3	9	19		16	38		11	2		30	29			27	14		
Milk	5	2	29	6	113	4			14			15					12	
Egg	9		8		104	6					1					1		
Sum	30	188	82	30	349	97	1,296	57	18	20	80	107	33	19	37	15	12	1,047

* Data originated from the NRP results of the corresponding countries submitted by livestock exporters in 2022 and 2023 and represents only countries with 10 or more violations of their country's MRL. For the 18 countries, country names are expressed in alphabetical letters.

Table 3. Classification of residue-violated substances in use from major importing countries

Usage	Countries*													
	A1	A2	B1	C1	C3	C5	E	G1	I2	M	N1	O	S2	U2
Antimicrobials	8	9	40		78	82	1296	12	36	10	34	2	32	909
Non detectable substances	3		2		304	15		24		2	53	2	4	1
Anticoccidials	6		7		160	64							5	
Non-steroidal anti-inflammatory drugs	4	11	1		8			30		1	1			154
Antiparasitic	1		30	6	27	2		3		9	4	28		9
Heavy metals			1			93								
Growth promoters			11	4	17					49				
Anabolic steroids	7	26								2	3		1	
Antipyretic analgesics		1				6		8			20			
Bronchodilators (muscle building)					1	1				22				
Synthetic hormone	3			16								1		
Natural hormones	3					8					1			
Glucocorticoids								6			1			
Insecticide										4				1
Steroid precursors				4										
Beta-adrenergic agonists										2				
Sedatives		1												
Opioid pain medications														1
Rodenticides											1			
Others														
Sum	35	48	92	30	595	271	1,296	83	36	101	118	33	42	1,075

* Data represents only countries with 10 or more violations of their country's MRL. For the 18 countries, country names are expressed in alphabetical letters.

Table 4. Categorization by usage of residue-violated substances in beef from major importing countries

Usage	Countries*													
	A1	A2	B1	C1	C3	C5	E	G1	I2	M	N1	O	S1	U2
Antimicrobials		5			5	22	1,296	1	20	3	7	2	7	871
Nonsteroidal anti-inflammatory		2			3			29			1			148
Non detectable substances					44	4					46	2	4	1
Antiparasitic	1		18		2			2		6		28		9
Growth promoters			4	4	11					26				
Anabolic steroids	6	10				4					1			
Synthetic hormone	3			16								1		
Bronchodilators (muscle building)										14				
Antipyretic analgesics								8			4			
Natural hormones	3					8								
Anticoccidials					2								8	
Heavy metals						9		6						
Glucocorticoids				4										
Steroid precursors														
Skin care														
Insecticides														
Opioid pain medications														1
Sum	13	17	22	24	67	47	1,296	46	20	49	59	33	19	1,030

* Data represents only countries with 10 or more violations of their country's MRL. For the 18 countries, country names are expressed in alphabetical letters.

Table 5. Categorization by usage of residue-violated substances in poultry meat from major importing countries

Usage	Countries*																	Sum
	A1	A2	A3	B1	C3	C5	G1	I2	J	M	N1	R	S2	S4	T1	T2	U1	
Anticoccidials	2		1	6	35	42									1			87
Antimicrobials				3		12		16	1	1	7	3	15			1	1	60
Non detectable substances					18	1					3							22
Growth promoters					5					2								7
Heavy metals				1		5												6
Non-steroidal anti-inflammatory drugs		4												1				5
Antiparasitic					1		1			2								4
Antipyretic analgesics		1																1
Sum	2	5	1	10	59	60	1	16	1	5	10	3	15	1	1	1	1	192

* For the 18 countries, country names are expressed in alphabetical letters.

Table 6. Categorization by usage of residue-violated substances in pork from major importing countries

Usage	Countries*																	Sum
	A1	A2	A3	B1	B2	C3	C5	G1	I1	M	N1	P	R	S2	S3	U1	U2	
Antimicrobials	2	1	5	12		4	26	11	1	4	18	2	1	17	1	1	12	118
Non detectable substances	1					6	6		1	1	2			4	4	1		26
Growth promoters				7						18								25
Anabolic steroids		6					2			2	2			1	9			22
Antiparasitic						3	2			1	4							10
Non-steroidal anti-inflammatory drugs		2			1	2											5	10
Anticoccidials						1								5				6
Bronchodilators (muscle building)										4								4
Heavy metals							2											2
Natural hormones											1							1
Rodenticides											1							1
Sum	3	9	5	19	1	16	38	11	2	30	28	2	1	27	14	2	17	225

* For the 18 countries, country names are expressed in alphabetical letters.

Table 7. Categorization by usage of residue-violated substances in milk from major importing countries

Usage	Countries*															Sum
	A1	A2	B1	B2	C1	C2	C3	C5	G2	I1	N1	N2	R	T3	U1	
Non detectable substances						1	99									100
Antiparasitic			12		6		8			10				6	3	45
Antimicrobials	1	2	16				4	3		4		2	1	6		39
Non-steroidal anti-inflammatory drugs	4		1	6		4	2		1							18
Antipyretic analgesics											15					15
Heavy metals								1								1
Sum	5	2	29	6	6	5	113	4	1	14	15	2	1	12	3	218

* For the 18 countries, country names are expressed in alphabetical letters.

Table 8. Categorization by usage of residue-violated substances in eggs from major importing countries

Usage	Countries*												Sum
	A1	A3	B1	C3	C5	D	H	L	M	S3	T1	U1	
Anticoccidials	4		1	104	5	1	3			1	3	1	123
Antimicrobials	5	1	7		1	1		3					18
Non detectable substances									1				1
Sum	9	1	8	104	6	2	3	3	1	1	3	1	142

* For the 18 countries, country names are expressed in alphabetical letters.

steroidal anti-inflammatory drugs, antiparasitic drugs, and growth promoters were the main violations in beef. Many substances that are classified as non-detectable in Korea were also detected. In some countries, anabolic steroids and synthetic hormones have been detected (Table 4). In poultry, anticoccidials and antimicrobials were the main offending substances, with some substances listed as non-detectable in Korean food. Heavy metals and antiparasitic substances were found in some countries (Table 5). In pork, antimicrobials, growth promoters, anabolic steroids, anthelmintics, and non-steroidal anti-inflammatory drugs were the main violating substances. Substances that were not detected in Korean food were also detected, and growth promoters and non-steroidal anti-inflammatory drugs were violated in some countries (Table 6). In milk, 99 cases of substances designated as non-detectable in food products in Korea were detected in one country, including anthelmintics, antibacterial substances, non-steroidal anti-inflammatory drugs, and antipyretic analgesics (Table 7). In eggs, anti-coccidia and antibiotics were mainly violated, and in two countries, substances that are not allowed in food in Korea were detected (Table 8).

Major veterinary drugs and environmental contaminants violated of maximum residue limit in livestock products

The ranking of the offending substances across all livestock products was streptomycin (601 cases), benzylpenicillin (407), thiouracil (338), dihydrostreptomycin (279), neomycin (242), nicarbazin (186), gentamicin (151), sulfonamides (145), ceftiofur (113), and flunixin (108).

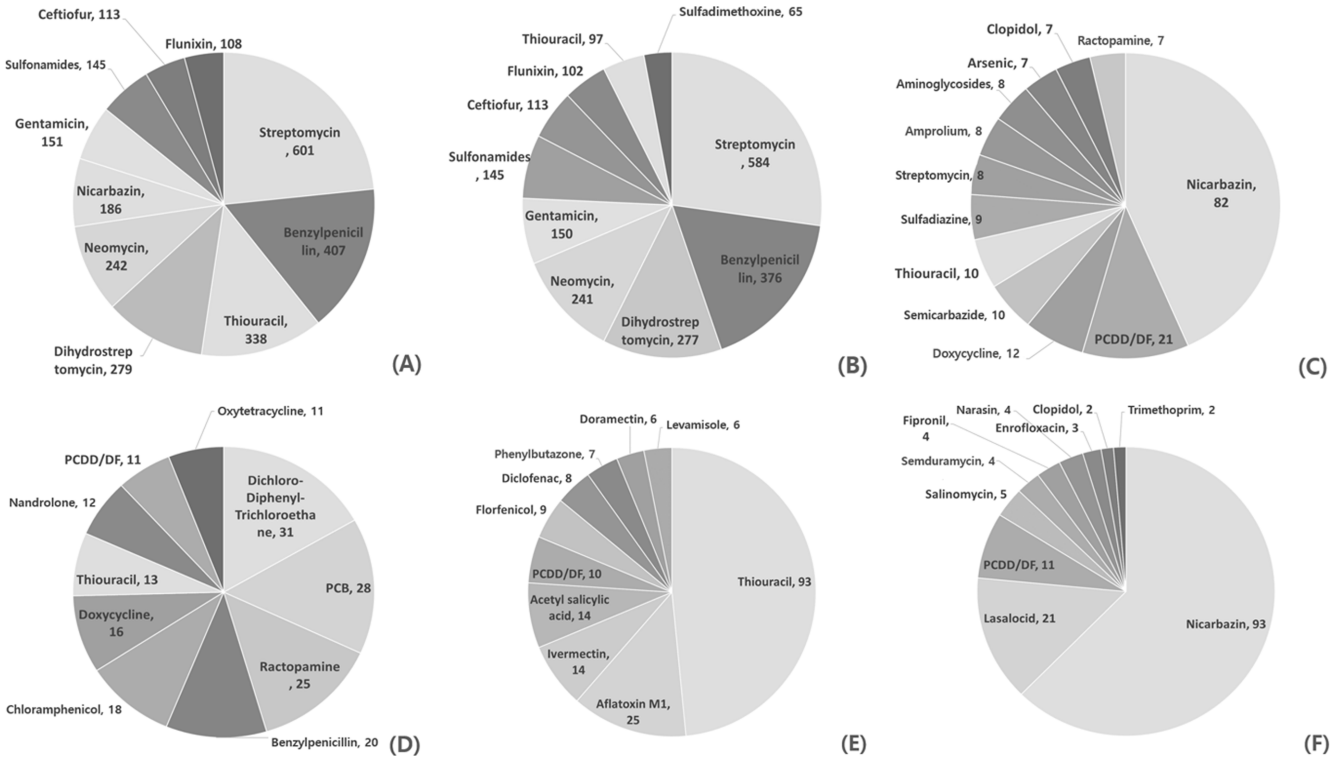

Fig. 1. Top 10 violated substances in (B) Beef, (C) Poultry meat, (D) Pork, (E) Milk, (F) Eggs and totally in (A) Livestock products.

In beef, streptomycin (584 cases), benzylpenicillin (376), dihydrostreptomycin (277), neomycin (241), and gentamicin (150). Sulfonamides (145), ceftiofur (113), flunixin (102), thiouracil (97), and sulfadimethoxine (65 cases). In pork, dihydrostreptomycin (31 cases), polychlorinated biphenyls (PCBs) (28), ractopamine (25), benzylpenicillin (20), chloramphenicol (18), doxycycline (16), thiouracil (13), nandrolone (12), PCDD/DF(polychlorinated dibenzodioxins/dibenzo-furans) (11), and oxytetracycline (11) were used. In poultry, nicarbazin (82 cases), PCDD/DF (21), doxycycline (12), semicarbazide (10), thiouracil (10), sulfadiazine (9), streptomycin, amprolium, and aminoglycoside (8) were violated, along with arsenic, clopidol, and ractopamine in addition. In eggs, nicarbazin (93 cases), lasalocid (21), PCDD/DF (11), salinomycin (5), semduramicin, fipronil and narasin (4), enrofloxacin (3), clopidol and trimethoprim (2) were violated. In milk, thiouracil (93 cases), aflatoxin M1 (25), ivermectin (14), acetylsalicylic acid (14), PCDD/DF (10), florfenicol (9), diclofenac (8), phenylbutazone (7), doramectin (6), and levamisole (6) were violated (Fig. 1).

Discussion

While veterinary drugs are highly effective in treating and preventing livestock diseases, they can persist in animal-derived foods and pose a significant risk to human health. The NRP is a program conducted by each country to protect the health of its citizens and import safer livestock products from livestock-importing countries. It inspects for residues in livestock products that can affect health.

Kang et al.[11] investigated the residues of veterinary drugs for which no residue limits had been established at the time in domestic and imported livestock products and reported the detection of acetylsalicylic acid, paracetamol, clopidol, diclazuril, amprolium, toltrazuril, and phenylbutazone. Also in Japan, Yamamoto et al.[12] reported that nitrofuran and chloramphenicol were detected in seafood mainly imported from Asian countries as a result of monitoring for veterinary drug residues in seafood products from home and importing countries prior to the introduction of the positive list system.

According to an analysis of NRP data from 2019 to 2022 from countries exporting livestock products to South Korea, 241 residues of neomycin, 183 penicillin G, 151 gentamicin, 113 ceftiofur, and 103 nicarbazin were found to be in violation of the permissible residue limits, mostly for antibiotics used to treat diseases. In terms of residues by country, neomycin increased sharply from 1 to 181 cases from 2019 to 2021, but decreased to 22 cases in 2022. Gentamicin increased from 2 cases in 2020 to 144 cases in 2021, but decreased to 5 cases in 2022, likely due to a gentamicin violation in milk from certain countries in 2021. Ceftiofur was detected in 133 cases in 2022, while flunixin has been consistently detected since 2020, along with florfenicol, meloxicam, and ractopamine. The types of substances found to be in violation of the MRL differed by region. For example, Europe mainly detected anabolic steroids, while North and South America found growth promoters along with antibiotics. The results of the analysis of residue violations by major countries showed that antibiotics such as penicillin G, ceftiofur, neomycin, and florfenicol, as well as anti-inflammatory drugs such as meloxicam and flunixin, were mainly violated in the U2 country. However, in the C5 country, PCDD/DF, dichloro diphenyl trichloroethane (DDT), PCBs, arsenic, as well as antioxidants such as nicarbazin, antibacterials such as streptomycin, penicillin, and tetracyclines, and some non-detectable substances such as thiouracil are present. In the G1 country, environmental contaminants such as PCDD/DF, DDT, and hexachlorobenzene, anti-inflammatory drugs such as diclofenac, meloxicam, and dexamethasone, and antipyretic drugs such as sulpyrine and ketoprofen were mainly violated. Chloramphenicol, an undetectable substance in Korea, was found to violate the residue limit. In M country, hormones used to promote growth and induce pregnancy, such as zilpaterol, ractopamine, and clenbuterol, were found to be highly violated; mebendazole, ivermectin, florfenicol, and sulfamethazine, which are used as antiparasitic and antifungal drugs; and nitrofurans and furazolidone, which are not used in Korea, were also violated. In B1 country, ivermectin and nicarbazin, used for the treatment of coccidiosis, showed high violations, as did growth promoters such as ractopamine, anthelmintics such as doramectin and abamectin, and other substances such as anti-inflammatory drugs such as florfenicol, sulfa-drugs, and doxycycline. Taken together, the differences in detected substances across countries are largely due to differences in the main livestock species in each country and differences in authorized veterinary drugs. For example, in countries with many dairy cows, many veterinary drugs used for disease management, such as antibiotics and antipyretic analgesics, are detected. In contrast, in countries with many beef cows and pigs, veterinary drugs used for growth promotion, in addition to antibiotics, are primarily detected. In countries with many chickens, veterinary drugs used to treat coccidia were the most commonly detected substances. While residue violations were reported in many countries for veterinary drugs, violations for environmental contaminants such as dioxins and PCBs were mainly reported in European countries. This may be because these countries conduct more residue testing for environmental contaminants such as dioxins than other countries[13].

The highest number of residue violations by livestock

products was in cattle, with 1,056 violations in beef, 245 in pork, 106 in poultry meat, 389 in milk, and 103 in eggs. In beef, penicillin G had the highest number of violations, likely due to the high use of antibiotics to treat mastitis in dairy cows. In milk, neomycin and gentamicin showed an unusual trend, with 144 violations in E country in 2021. This is likely related to the more individualized nature of cattle management, which is characterized by individualized treatment. In this study, antibiotics such as streptomycin, benzylpenicillin, dihydrostreptomycin, neomycin, gentamicin, sulfonamides, and ceftiofur were mainly found in beef, which is believed to be because these drugs are administered to cattle individually for the treatment of bacterial infections and mastitis[14].

On the other hand, environmental contaminants such as DDT, PCBs, PCDD/DF, were detected in pork, and other drugs used for growth promotion and pregnancy induction, such as ractopamine and nandrolone, were mainly residue violations. This is likely due to the residue of environmental contaminants in pigs through feed during the pig breeding process[15], or the use of growth-promoting and hormonal drugs for fattening or pregnancy induction[16].

In poultry meat and eggs, nicarbazin, which is used as an anti-coccidial agent, was detected at the highest level, but unlike poultry meat, other anti-coccidial components such as lasalocid, semduramicin, and narasin were found in eggs, which is judged to be due to the characteristics that these substances are better transferred to eggs than meat[17].

Aflatoxin M1 was detected in the milk, and it is believed that aflatoxin B1 was contaminated in the feed and metabolized in the body and excreted in the milk[18,19].

In addition, acetylsalicylic acid, diclofenac, and phenylbutazone, which are used for antipyretic analgesia, were detected in the milk, suggesting that these drugs were used for antipyretic analgesic due to infectious diseases such as mastitis[20,21]. In particular, a significant amount of thiouracil, which is designated as a non-detectable substance in food in Korea, was detected in livestock products. It is believed to be used in some countries to increase livestock productivity.

Although the causes of residue violations in each country were not investigated in this study, the causes of residue violations of animal drugs in livestock products are known to be non-observance of the withdrawal periods, off-label use, and illegal use. It is recommended that further investigation is necessary to analyze the causes of residue in order to reduce residues in each country[22].

Conclusively, the present study is expected to provide a more scientific and efficient basis for the annual national residue inspection program for imported livestock products by providing substances that should be strengthened by country and livestock product in the process of inspecting veterinary drugs in imported livestock products in Korea.

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국문요약

우리나라에 축산물을 수출한 국가들이 2022년과 2023년에 제출한 2019-2022년 국가별 잔류물질검사프로그램(NRP) 자료를 바탕으로 축산물 유형별, 국가별로 잔류허용기준을 위반한 동물용의약품과 환경오염물질의 현황을 분석하였다. 가장 많이 위반된 잔류물질은 네오마이신 241건, 페니실린G 183건, 겐타마이신 151건, 세프티오퍼 113건, 니카바진 103건 등이였고 축산물별로는 소고기, 돼지고기, 가금육, 우유, 계란 등의 순서로 나타났다. 잔류 위반이 가장 많았던 소고기에서는 페니실린G, 세프티오퍼, 플루니신, 네오마이신, 벤질페니실린, 멜록시캄, 플로르페니콜, 질파테롤 등 전염병 치료에 사용되는 항생제와 해열제 및 성장 촉진에 사용되는 동물용의약품이 주로 검출되었지만, 돼지고기에서는 성장촉진을 목적으로 사용되는 락토파민과 항생제인 독시사이클린, 클로람페니콜, 벤질페니실린, 난드롤론, 티오라실, 스트렙토마이신 및 임신 촉진에 사용되는 호르몬이 가장 흔하게 검출된 것으로 나타났다. 가금육에서는 콕시듐증 치료에 사용되는 항생제인 니카바진이 가장 많이 위반되었으며, 스트렙토마이신, 아미노글리코사이드 항생제, 벤질페니실린, 독시사이클린 및 기타 항생제가 그 뒤를 이었다. 동물용의약품의 잔류 위반은 많은 국가에서 보고되고 있으나, 다이옥신과 PCB와 같은 환경오염 물질의 잔류는 주로 유럽 국가에서 보고되었다. 국가별 잔류물질의 차이는 각국에서 사육되는 가축과 사육관리 방식의 차이에 의한 것으로, 소고기의 잔류 수준이 높은 것은 소는 다른 동물에 비해 질병 발생 시 개체별로 치료되기 때문일 것으로 추정된다. 본 연구 결과는 수입 축산물의 안전성 확보를 위하여 국가별, 축산물별로 중점적으로 검사가 필요한 물질을 제시함으로써 매년 실시하는 수입 축산물 잔류물질검사를 보다 과학적이고 효율적으로 수행할 수 있는 기반을 제공하였다.

Conflict of interests

The authors declare no potential conflict of interest.

ORCID

Su Min Nam https://orcid.org/0009-0001-8891-3415
Su Jin Pyo https://orcid.org/0009-0007-2876-2444
Hyoung Joon Moon https://orcid.org/0000-0001-6211-8758
Hwan Goo Kang https://orcid.org/0000-0002-6689-0080
Sung Hee Choi https://orcid.org/0000-0003-0323-7575

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