Environmental Research 194 (2021) 110635

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Review article

A review of chemical and microbial contamination in food: What are the threats to a circular food system?

Astha Thakali, Jean D. MacRae *

Department of Civil and Environmental Engineering, University of Maine, 5711 Boardman Hall, Orono, ME, 04469, USA

ARTICLE INFO

Keywords:
Food waste recycling
Contaminants in food and food waste
Contaminants in compost and digestate
Microbial contamination in food and food waste
And chemical contaminants in food and food waste

ABSTRACT

A circular food system is one in which food waste is processed to recover plant nutrients and returned to the soil to enable the production of more food, rather than being diverted to landfill or incineration. The approach may be used to reduce energy and water use in food production and contribute to the sustainability of the system. Anaerobic digestion and composting are common food waste treatment technologies used to stabilize waste and produce residual materials that can replenish the soil, thus contributing to a circular food system. This approach can only be deemed safe and feasible, however, if food waste is uncontaminated or any contaminants are destroyed during treatment. This review brings together information on several contaminant classes at different stages of the food supply chain, their possible sources, and their fates during composting and digestion. The main aim is to identify factors that could impede the transition towards a safe, reliable and efficient circular food system. We investigated heavy metals, halogenated organic compounds, foodborne pathogens and antibiotic resistance genes (ARGs) in the food system and their fates during digestion and composting. Production and processing stages were identified as major entry points for these classes of contaminants. Heavy metals and foodborne pathogens pose less risk in a circular system than halogenated organics or antibiotic resistance. Given the diversity of properties among halogenated organic compounds, there is conflicting evidence about their fate during treatment. There are relatively few studies on the fate of ARGs during treatment, and these have produced variable results, indicating a need for more research to clarify their fate in the final products. Repeated land application of contaminated food waste residuals can increase the risk of accumulation and jeopardize the safety of a circular food system. Thus, careful management of the system and research into the fate of the contaminants during treatment is needed.

1. Introduction

About a third of the food produced globally goes to waste each year (Gustavsson et al., 2011). This loss is fundamentally unsustainable due to the water, energy and material consumption required for the production, processing, storage and transport of food that is not productively used (Pleissner, 2018). The food waste management hierarchy puts reuse as the preferred option if food is still qualitatively good enough for human consumption, meaning excess food should be diverted to people who need it, whenever feasible (Garcia-Garcia et al., 2017). The U.S. Department of Agriculture estimated that 11.8 percent, or 15 million households, had problems providing enough food in 2017 (U.S. EPA, 2020). When excess food at any stage of the food system can't be diverted to people in need, the next best option is to feed it to animals. Even with the best systems in place to develop an efficient food system, there will always be some fraction that is not fit for consumption. This material should be recycled and reused to minimize the environmental burden and allow for recovery of part of the resources initially used in its production, processing and transport (Pleissner, 2018), creating a more circular food system (Fig. 1).

Food waste generated during production includes damaged or low-value products left in the field. Food is wasted during processing due to damage during transport, spoilage or contamination during storage, and losses during processing. The retail system generates food waste due to handling-related damage, lack of cold storage, and poor inventory control. Food waste generated at the consumer level is due to over-purchasing, poor storage, over-preparation, portioning, or cooking; and confusing labels (Girotto et al., 2015). In a linear system, the food waste at each stage would go to landfill or perhaps incineration. In a circular system (Fig. 1), food waste is recycled by treatment to stabilize

* Corresponding author.
E-mail addresses: amaine0625@gmail.com, asthathakali@gmail.com (A. Thakali), jean.macrae@maine.edu (J.D. MacRae).

https://doi.org/10.1016/j.envres.2020.110635
Received 9 July 2020; Accepted 14 December 2020
Available online 31 December 2020

the material and recover the remaining nutrients to replenish the soil. On-farm composting is an efficient, cost-effective technique using available farm tools to recycle wasted biomass at the source (Scotti et al., 2016). Food waste recycling is often infeasible at the consumer and retail levels, however, necessitating transport of food waste to landfill or treatment facilities.

Of municipal solid waste collected in 2017, only 6.3% of about 41 million tons of food waste generated in the US was diverted for composting (U.S. EPA, 2019). Food waste is associated with methane and odor emissions at landfills, air pollution from its incineration, water pollution due to runoff or leaching, energy loss and pollution from production, processing, transport, storage and waste collection, and loss of usable land occupied by landfills (Griffin et al., 2009). The more efficient, circular food system uses composting or anaerobic digestion (AD) to recover the nutrients, and some of the energy in the case of AD. AD is an anaerobic biological process that converts organic waste into methane and a stable digestate containing plant nutrients and organic matter. Composting is an aerobic biological process that decomposes the easily degraded organic waste components and produces a soil amendment that slowly releases plant nutrients and improves the water-holding capacity and texture of soil. Compost and digestate can be used as organic soil amendments to reduce the need for fertilizers in food production (Lin et al., 2018).

While a circular system uses resources more efficiently, the approach is not without risk. There are points of potential contamination at every stage of the food system. Diverting food waste to AD and composting for nutrient recovery will only be feasible and safe as long as the food waste is uncontaminated with other materials and toxicants, or the contaminants are destroyed by treatment. When contaminated food enters as feedstock for composting or anaerobic digestion and the residuals are used in agricultural soils, the contaminants can be taken up by the plants, resulting in human exposures (Cerda et al., 2018; Clarke and Cummins, 2015; Cortney Miller, Heringa, Kim and Jiang, 2013).

The aims of this review are: (1) to bring together the information on several different classes of contaminants that have been measured in food at different stages along the food supply chain, (2) to identify possible pathways of contamination of our food system that could amplify the contamination over time, and (3) identify the risk factors that could impede progress toward a safe and efficient circular food system. The contaminants included were selected based on their potential to cause health risks upon exposure. To our knowledge, this review is the first to consider both chemical and biological contaminants in a circular food system.

2. Contaminants in food

2.1. Heavy metals

Heavy metals are conductive elements having a density greater than 4.5 g/cm^3 (Logan et al., 1999). Some heavy metals are essential micronutrients with beneficial impacts on growth as long as their concentrations remain low, however at high concentrations, heavy metals are toxic to plants, animals and humans (Epstein et al., 1992; Garcia, Herñ ndez*, & Costa, 1990).

In aquatic systems, heavy metals are redistributed throughout the water column and sediment, and may accumulate in fish and other edible aquatic biota (Makedonski et al., 2017). Likewise, in terrestrial systems, contaminants can be absorbed and accumulate in edible and non-edible plant tissues during growth. Cadmium (Cd) is highly mobile, poorly adsorbed to soil and phytoavailable, and therefore often detected in the above-ground parts of plants (Hajeb et al., 2014). Higher bioaccumulation factors (BCFs) have been observed for leafy vegetables than other kinds of plants in many studies, suggesting a strong ability of these plants to accumulate metals from soil (Dziubanek et al., 2015; Lian et al., 2019). Table 1 shows the range of heavy metals detected in food obtained in a US Food and Drug Administration (USFDA) study that included samples from all parts of the country, all seasons, and multiple sources (supermarkets, grocery stores and fast food restaurants) in 2017.

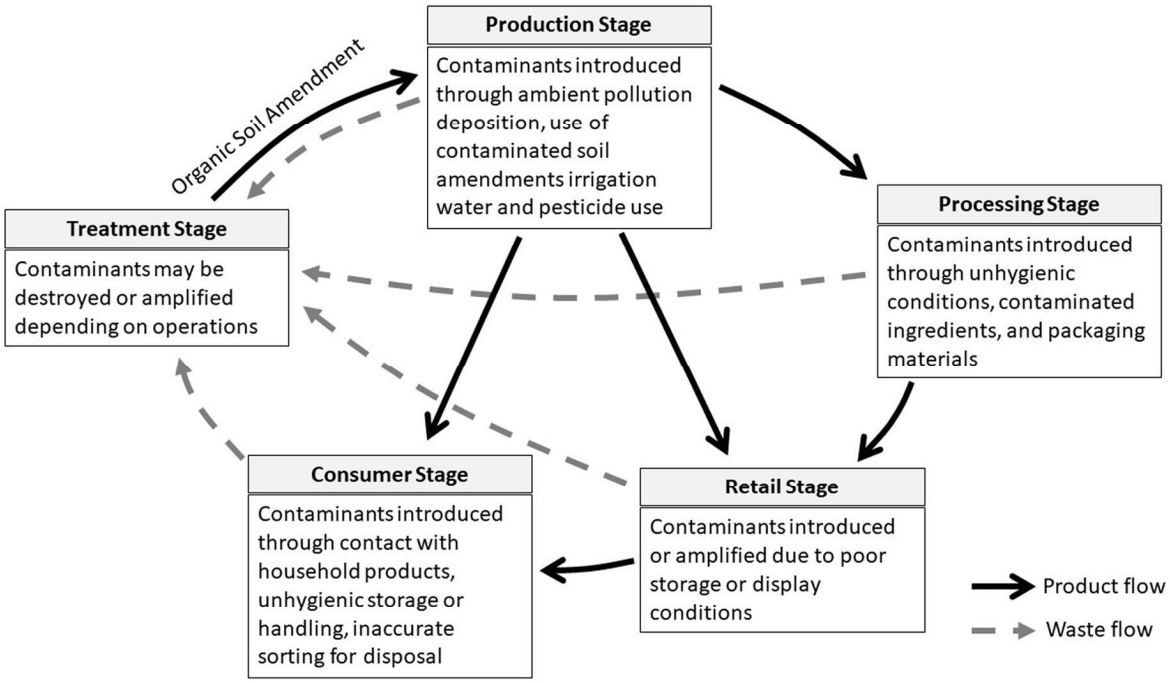

Fig. 1. Circular food system with possible sources of contamination at each stage. Food is produced from soil, water, fertilizer, feed and potentially other inputs, in the production stage. In the processing stage, harvested food may be washed, prepared and/or packaged. At the retail stage, food is stored, perhaps further packaged, displayed and sold. At the consumer stage, food is stored, prepared, cooked and consumed. Food waste (light arrows) can be generated at every stage and sent for treatment. (anaerobic digestion or composting) prior to recycling. The end products of treatment are used as organic fertilizers, circularizing the food system. Contaminants entering the circular food system at each stage (boxes) might be also recycled.

Table 1
Range of heavy metals in US food.

Metals	Concentration (mg/kg)
Arsenic (As)	0–4.23
Cadmium (Cd)	0–0.477
Chromium (Cr)	0–0.959
Copper (Cu)	0–161
Lead (Pb)	0–0.036
Mercury (Hg)	0–0.062
Nickel (Ni)	0–5.4
Zinc (Zn)	0–216

(U.S. Food and Drug Administration, 2019)

Baked cod, pan cooked ground beef, pan cooked liver (beef/calf), and canned tuna were the foods with the highest heavy metal concentrations.

2.1.1. Sources of heavy metals in food

Sources of heavy metals in the production stage include proximity to industrial areas and aerial deposition, irrigation with contaminated water, which includes discharge from wastewater treatment plants, industrial and road runoff into the field, and food produced using a high amount of phosphorus fertilizer (Dziubanek et al., 2015; Khan et al., 2015; Lian et al., 2019; Margenat et al., 2018; McBride et al., 2014; Zuliani et al., 2019). Sources of heavy metals in meat include metals introduced in feed, drinking water, and mineral supplements, especially when they are used in excess of recommended amounts (Abbas et al., 2019; Hajeb et al., 2014; Hu et al., 2018).

Heavy metals can also migrate into food from packaging materials (Filippinia et al., 2019). Canned food is especially prone to migration of tin, depending on the food pH, storage time, the temperature of the canned foods, exposure to air of opened canned food, corrosion of the can, and poor lacquering (Filippinia et al., 2019; Ikem and Egiebor, 2005). Packaging materials produced with recycled materials like recycled polyethylene terephthalate can also contribute to heavy metal contamination and migration (Whitt et al., 2016). Cooking processes like frying, grilling, boiling, etc. and pre-cooking processes such as the peeling of vegetables can also influence heavy metal levels (Hadayat et al., 2018; Hajeb et al., 2014; Perelló et al., 2008).

The range of concentrations of heavy metals measured in different countries and foods are shown in Table 2. The table captures data at production, processing and retail stages. Heavy metals have been detected at each stage of the food supply and in almost all kinds of food. Some of the data were reported on a wet weight basis, some on a dry weight basis, and a few did not specify. When the values were reported in wet weight, we assumed a moisture content of 70% (Chaz Miller, 2000), to convert to a presumed dry weight basis. If wet or dry weight basis was not stated, we assumed they were reported on a dry weight basis and did not adjust the values. The most stringent regulatory limits for contaminants in compost, and US EPA regulatory limits for land application of biosolids are given in Table 3. In the US there are no federally mandated regulatory limits for heavy metals in compost, however many states have developed their own limits. We have compared the heavy metal content in food with the most stringent compost regulatory limits. Heavy metals are persistent, and in fact increase in concentration during treatment due to the reduction in the organic content of the residual material (Kupper et al., 2014). However, we did not adjust concentrations for comparison to the compost standards. The values in bold in Table 2 exceeded the most stringent regulatory limits and represent a contamination risk to the system.

The highest concentrations Cd (3.63 mg/kg ww) (Liang et al., 2018), Lead (Pb) (38.8 mg/kg) (Khan et al., 2015)and arsenic (As) (52.48 mg/kg ww) (Traina et al., 2019) were seen in the samples taken from the retail stage of the food system. This is to be expected because food would retain all the contaminants at each prior stage, as well as those introduced during transportation, storage and display, unless the contamination is on the surface. Tin was highest in canned food (Ikem and Egiebor, 2005). Mercury (Hg) (6.605 mg/kg ww) (USEPA, 2009b), Chromium (Cr) (6.55 mg/kg ww) (Esposito et al., 2018), Zinc (Zn) (182 mg/kg ww) (Bortey-sam et al., 2015), Nickel (Ni) (24.65 mg/kg ww) (Esposito et al., 2018) and Copper (Cu) (224.3 mg/kg ww) (Bortey-sam et al., 2015), were highest in samples from the production stage. These samples were taken from areas impacted by illegal hazardous waste dumping, mining activities, industrial emissions, irrigation with contaminated wastewater or use of metal-based fertilizers and pesticides.

2.2. Halogenated compounds

Organohalogenated contaminants are usually synthetic organic chemicals with one or more halogens (chlorine, bromine, iodine and fluorine) substituted for hydrogens in the molecule. Many halogenated compounds are classified as persistent organic pollutants or POPs. POPs are resistant to environmental degradation (chemical, biological and photolytic) and therefore have a long half-life (Alharbi et al., 2018; Jones and Voogt, 1999). POPs tend to be hydrophobic and partition strongly to the solid matrix (organic matter) in the aquatic and soil environment. They also tend to partition into lipids in organisms, which slows their metabolism resulting in accumulation in food chains (Jones and Voogt, 1999). Many are volatile or semi-volatile, and migrate from soils, vegetation, and aquatic bodies into the atmosphere. Volatilization enables them to travel long distances and deposit far from the source (Jones and Voogt, 1999). Examples of POPs include pesticides such as organochlorine pesticides (OCPs), industrial chemicals like polybrominated diphenyl ethers (PBDEs), and hexabromocyclododecane (HBCD), and by-products of industrial processes, such as dioxins and furans. These contaminants are persistent and ubiquitously present in the environment (Pedro et al., 2018; Schecter et al., 2010a,b), and many are associated with endocrine disruption, cancer and other toxic impacts (Jones and Voogt, 1999).

Poly and per fluorinated alkyl substances (PFASs) are a family of molecules consisting of linear or branched carbon chains that are fully or partially fluorinated. Fluoroalkyl substances have high thermal, chemical and biochemical stability due to the larger size of the fluorine atom compared to hydrogen, and the strength of the carbon-fluorine bond (Ghisi et al., 2019). They repel both water and oil, so they are used in paper coatings and packaging; as surface protection products used on carpet and clothing to resist stains and water; as nonstick coatings on cookware; as industrial surfactants; and in the manufacture of fire-resistant foams (Fair et al., 2019; Schecter et al., 2010a). PFASs have affinity for serum albumin and fatty acid binding protein and some show a bioaccumulation potential (Ahrens and Bundschuh, 2014; Haukas et al., 2007).

In the 2017 pesticide monitoring program, the USFDA analyzed 6069 foods (1799 domestic and 4270 imported) consumed by humans and found that 96.2% of domestic food and 89.6% of imported food samples were compliant with federal standards. No pesticides were detected in 52.5% and 50% of the domestic and imported samples respectively (U.S. Food and Drug Administration, 2017).

2.2.1. Sources of POPs in food

Sources of POPs contamination during the production of food crops include wastewater use for irrigation, runoff from contaminated sites to the fields, urban activities, pesticide and fertilizer use (Batt et al., 2017; Blocksom et al., 2010; Fair et al., 2019; Ghisi et al., 2019; Nerín et al., 2016; Rather et al., 2017). Other sources of OCPs and polychlorinated biphenyl (PCB) contamination can be due to proximity to toxic waste sources and atmospheric deposition (Olatunji, 2019; Witczak & Abdel-gawad, 2012). Shorter chain PFASs accumulate in leaves and fruits whereas longer chain compounds tend to accumulate in roots (Ghisi et al., 2019; Scher et al., 2018). Perfluorobutyrate (PFBA), Perfluoropentanoic acid (PFPeA), Perfluorohexanoic acid (PFHxA) and

Table 2
Range of heavy metals detected in foods at different stages of food supply chain.

Country	Food (unit, weight)	Site Characteristics	Concentration	Author
Production Stage				
USA	Vegetables (mg/kg, ww)	Urban farms from Buffalo, New York	Cd: 0.0021–**0.36** Pb: 0.0023–2.1	McBride et al. (2014)
USA	Vegetables (mg/kg, ww)	Urban and sub-urban farms	Cd: <LOD[A]-0.133 Pb: <Limit of detection (LOD)-0.180	Kohrman & Chamberlain (2014)
USA	Fish (mg/kg, ww)	Lakes and reservoirs nationwide	Hg: 0.005-**6.605**	USEPA (2009a)
Bangladesh	Fish (mg/kg ww)	River impacted by surrounding anthropogenic activities	As: 0.001–0.002 Cr: 0–0.01 Hg: 0.004–0.007	Hossain et al. (2018)
China	Vegetable (mg/kg, ww)	Impacted by surrounding anthropogenic activities	Cd:0.01-**0.66**, Hg: 0.001–0.043 Pb: 0.01–1.53 Zn: 3.14–58.85	Lian et al. (2019)
China	Milk (μg/L, ww)	Industrialized and preserved region as control	As: 0.002–1.53 Cd: 0.01–**0.27** Cr: 0.02–5.01, Pb: 0.03–10.46	Zhou et al. (2019)
Ghana	Meat (mg/kg, ww)	Gold and manganese mined area	As: nd[B]-0.37 Cd: nd-**2.26** Cr: nd-1.35 Cu: 0.28-**224.3** Hg: nd-**0.28**, Ni: nd-1.29 Pb: nd-3.70 Zn: 3.8-**182.2**	Bortey-sam et al. (2015)
India	Chicken and eggs (mg/kg, ww)	Copper mining and processing facilities	Cr: 0.16–1.63 Cu: 0.77-**48.79** Manganese (Mn): 0.36–4.67 Ni: 0.13–2.86 Pb: 0.01–2 Selenium (Se): 0.14–1.52 Zn: 6.58-**72.79**	Girihttps & Singh (2019)
Italy	Fresh produce (mg/kg, ww)	Illegal dumping of hazardous waste	As: 0.0005–0.4590 Cd: 0.0005–**0.2150** Cr: 0.0005–6.5490 Cu: 0.0005-**77.8690** Hg: 0.0005-**1.4900** Ni: 0.0005-**24.6520** Pb: 0.0005–0.7630 Sn: 0.0005–8.4450 Titanium (Ti): 0.0005–7.3440 Zn: 0.0005-**162.5650**	(Esposito et al., 2018)
Philippines	Vegetables (mg/kg)	Illegal gold mining	Cd: 0.05904–0.69678 Pb: 0.03889–0.49208	Palisoc et al. (2018)
Poland	Vegetables (mg/kg, ww)	Industrialized and impacted by mining	Cd: <0.0600-**1.70** Pb: <0.0400–3.88	Dziubanek et al. (2015)
Spain	Lettuce (mg/kg, ww)	Peri-urban with anthropogenic activities and rural site	As: 0.0000575–0.00230 Cd: 0.004–0.04 Cu: 0.40–0.96 Hg: 0.000301–0.00167 Ni: 0.04–0.61 Pb:0.03–0.45 Zn: 1–3.41	Margenat et al. (2018)
Slovenia	Fish (mg/kg, dw, range of mean)	Anthropogenic and mineral weathering and hydromorphological pressure	As: nd-0.775 Cd: nd-0.0525 Cr: 0.035–0.931 Cu: 0.58–6.45 Hg: 0.027-**5.12** Methylmercury (MeHg): 0.027–4.25) Pb: nd-0.547 Zn: 18.3–105	Zuliani et al. (2019)
Processing Stage				
USA	Canned fish (mg/kg, ww)		Ag: 0–0.20 As: 0–1.72 Cd: 0–0.05 Co: 0–0.10 Cr: 0–0.30 Cu: 0.01–20.5 Hg: 0.02–**0.74** Pb: 0–0.03 Mn: 0.01–2.55 Ni: 0–0.78	Ikem & Egiebor (2005)

(*continued on next page*)

Table 2 (*continued*)

Country	Food (unit, weight)	Site Characteristics	Concentration	Author
			Sn: 0.04–28.7 Vanadium: 0–0.31 Zn: 0.14-**97.8**	
Italy	Canned food, median value (mg/kg)		Sn: 0–0.017	Filippinia et al. (2019)
Spain	Cooking effects (mg/kg)		Before Cooking: As: 0.050–2.086 Cd: nd-0.007 Hg: nd-**0.355** Pb: nd-0.084 after cooking: As: 0.092-**3.281** Cd: nd-0.012 Hg: nd-**0.421** Pb: nd-0.060	Perelló et al. (2008)
Retail Stage				
USA	Fish (mg/kg, ww, mean range)		As: 0.23-**3.3** Cd: 0.00013–0.02 Cr: 0.03–0.34 Hg: 0.01–**0.65** Pb: 0.04–0.34	Burger & Gochfeld (2005)
USA	Vegetables (mg/kg)		Cd: <0.1 Cr: <0.1 Cu: 0.6–30 Ni: <0.04 Pb: 4.1–27 Zn: 1.7–65	Mehari et al. (2015)
USA	Vegetables (mg/kg, ww)		As: 0.00120–0.020 Cd: 0.00062–0.057 Cu: 0.127–2.654 Ni: 0.005–0.291 Pb: 0.0005–0.070 Zn: 1.125–3.950	Hadayat et al. (2018)
USA	Produce (mg/kg, ww)		Cd: <LOD-0.051 Pb: <LOD-0.057	Kohrman & Chamberlain (2014)
Bulgaria	Fish (fillet mean concentration mg/kg, ww)	Black sea having pollution issue	As: 0.38–1.1, Cd: <0.010–0.015 Cu: 0.34–1.4 Hg: 0.05–**0.16** Pb: <0.06–0.08 Zn: 5.2–11	Makedonski et al. (2017)
China	Vegetables (mg/kg, ww)	Industrial area	As: <LOD-0.7340 Cd: <LOD-**3.63** Cr: <LOD-1.28 Hg: <LOD-**0.6100** Pb: <LOD-3.0500	Liang et al. (2018)
China	Foodstuff derived from animals (mg/kg, ww)	Industrial area	As: 0.0030–1.8 Cd: 0.0004–**0.352** Hg: nd-0.037 Pb: 0.035–0.055	Wu et al. (2016)
Italy	Seafood (mg/kg, ww)		As: 5.35-**52.48** Cd: <0.01–0.14 Hg: 0.04–**0.84** Pb: <0.001–0.21	Traina et al. (2019)
Pakistan	Vegetables (mg/kg)	Industrial and anthropogenic activities	Cd: 0.11-**3.9** Cr: 0.7–7.2 Cu: 0.1–3.9 Ni: 1.1–7.1 Pb: 7.3–38.8 Zn: 2.9–27.5	Khan et al. (2015)
Portugal	Different food (mg/kg, ww, range of mean)		As: 0.003-**16.70** Cd: <LOQ-**0.30810** Pb: 0.00371–0.19218	Ventura et al. (2018)
Romania	Pork (mg/kg)		Cd: 0.04–**0.24** Cu: 0.65–1.55 Pb: 0.35–1.06 Zn: 23.1–62.1	Hoha et al. (2014)
Taiwan	Livestock meat (mg/kg)		As: <0.002–0.075 Cd: <0.002–0.103 Pb: <0.002–0.321	Chen et al. (2013)
Turkey	Fish (mean concentration) (mg/kg, ww)		Cd: 0.008-**1.122** Cu: 0.234–9.487 Hg: 0.0074-**1.75** Pb: 0.019–0.822	Keskin et al. (2007)

Numbers in bold font exceed the most stringent regulatory limit for compost (see Table 3).
A: Limit of detection, B: non-detection.

Table 3
Regulatory levels of heavy metals in compost.

Heavy metals	US EPA CFR 40/503 Sludge Rule (mg/kg dw)	Most stringent Limits (mg/kg dw)	Country
Arsenic (As)	41	10	EU Eco Label
Cadmium (Cd)	39	0.7	EC Reg. n 2092/91
Chromium (Cr)	No limit	50	Netherlands
Copper (Cu)	1500	70	EC Reg. n 2092/91
Lead (Pb)	300	45	EC Reg. n 2092/91
Mercury (Hg)	17	0.3	Netherlands
Nickel (Ni)	420	20	Netherlands and Belgium
Zinc (Zn)	2800	200	EC Reg. n 2092/91

(Hogg et al., 2009)

Perfluorooctanoic acid (PFOA) are the major PFASs detected in water and produce samples (Scher et al., 2018). However there are relatively few studies on this subject and more research is necessary to fully understand plant uptake (Scher et al., 2018).

For livestock, grazing on contaminated soil and grass, proximity to chemical production areas, and local exposure routes such as paints, sealants and coatings used in the structures in which the animals are housed, are some of the routes of exposure in addition to contaminated feed and water (Ferrante et al., 2017; Pajurek, Pietron, Maszewski, Mikolajczyk, & Piskorska-pliszczynska, 2019; Weber et al., 2018; Zennegg, 2018).

Packaging and processing practices are possible sources of POPs in food (Jogsten et al., 2009; Schecter et al., 2010a,b; Wang and Kannan, 2018). More than 6000 chemicals can be used in food contact materials in the US and European Union (EU). Migration of chemicals can occur from packaging materials into food (Nerín et al., 2016). There is always a chance that harmful, non-intentionally added substances (NIAS) may migrate from recycled packages (Geueke et al., 2014). Also, deterioration of packaging speeds up when stored under direct sunlight, which likely increases the rate of migration of contaminants into food (Rather et al., 2017).

In a lab experiment examining 15 food packaging materials containing PFOAs, these compounds were detected in the food in all cases. Significant PFOA migration occurred after only 2 h, and equilibrium was reached after 24 h (Xu et al., 2013). In another experiment on 407 samples of food packaging materials collected from five regions of the US, 33% had detectable fluorine (F) concentrations ranging from 16 to 800 nmol of F/cm^2 (Schaider et al., 2017). Fluorine was more commonly detected in grease-proof food contact papers, than in packages holding liquids or non-food-contact surfaces (Schaider et al., 2017). These examples show the potential for migration of PFAS from food packaging materials lined with PFAS.

Cooking processes can increase or decrease the concentration of POPs, with inconsistent results among studies, and no underlying mechanisms identified (Jogsten et al., 2009; Moon et al., 2019). PCBs can be formed from the reactions of polycyclic aromatic hydrocarbons (PAHs) with metallic components in ingredients or cookware under certain high temperature conditions (Moon et al., 2019). Thus, cooking processes can also become a source of POPs in food.

Halogenated compounds are found in foods at production, processing and retail stages as shown in Table 4. They have been detected in almost all kinds of food consumed worldwide. Most of the halogenated compounds are toxic at low concentrations and many bioaccumulate, so detection at even low levels is potentially dangerous for human health. PCB (857 ng/g ww), PBDE (311 ng/g ww) and Dichlorodiphenyltrichloroethane (DDT) (294 ng/g ww) levels were highest in fish collected

Table 4
Concentrations of Organohalogens detected in food worldwide.

Country	Food	Concentration	Author
Production Stage			
USA	Fish (ng/g, ww)	Σ Chlordane: nd- 311 ΣDDT: nd-294 ΣPBDE: nd-311 ΣPCB: nd-**857**	Batt et al. (2017)
USA	Fish (mean ng/g, ww)	ΣOCPs: 22.63 ΣPBDE: 1.9 ΣPCBs: **57.23** ΣPOPs: 81.76	Fair et al. (2018)
USA	Fish (ng/g, ww) (Range of mean)	Chlordane: 3.69–23.77 DDT: 5.47–18.32 Dieldrin: 2.66–5.17 PBDEs: 4.43–45.66 PCBs: 7.41-**123.12**	Blocksom et al. (2010)
USA	Fish (ng/g, ww)	PFOS: 2.53-**66.3** Total PFAS: 6.20–85.4 Total PFCA[A]: 3.40–23 Total PFSA[B]: 2.79–72.1	Fair et al. (2019)
USA	Fresh Produce (ng/g)	PFBA: nd-33 PFOA: nd-0.26 PFOS: nd-0.38	Scher et al. (2018)
Egypt	Cattle (ng/g,lw)	HCB[C]: 0.4–162 ΣCHLs[D]: 0.5–277 ΣDDTs: 1-308 Σdrins: 2-470 ΣHCHs[E]: 1-2827 ΣOCPs: nd-2827	(Mahmoud et al., 2016),
France	Hake (ng/g, dw.)	BDE-47: 0.09–65 CB-153: 2.7-**2154**	Bodiguel et al. (2008)
India	Rice (ng/g, dw	DDT: nd-110 HCH: 2-215	Babu et al. (2002)
Italy	Goat Milk (ng/g, ww)	HCB: nd-0.22 Σ20PCB: nd-7.34 Σ6PCB: nd-4.02 ΣDDT: nd-0.20	Ferrante et al. (2017)
Poland	Produce (range of mean ng/g, ww.)	Σ7PCBs: 0.12–3.71 DDT: 0.52–16.74 OCP: 21.57–190.63	Witczak & Abdel-gawad (2012)
Sava River Basin	Fish (ng/g, ww)	PBDEs: 0.65–11.5 PFBA[F]: <MLOQ[J]- 7.1 PFBS: <MLOQ- 3.5 PFOA: <MLOQ-**8** PFOS: <MLOQ-**17**	Ábalos et al. (2019)
South Africa	Produce (ng/g)	DDTs: 38.9–66.1 PCBs: 90.9-**234**	(Olatunji, 2019),
Processing Stage			
Korea	Seafood and different cooking methods (ng/g, ww)	PCB: 0.01–20.6	Moon et al. (2019)
Spain	Raw, cooked and packaged food (ng/g, ww)	PFHxS[G]: <0.001-<0.250 PFHxA: <0.001–0.160 PFOA: <0.063-<0.675 PFOS: <0.001–0.330	Jogsten et al. (2009)
Retail Stage			
USA	Meat, fish, dairy, cheese and vegetables (ng/g, ww)	Dieldrin: nd-2.30 p, p'-DDTs: nd-0.45 PCBs: nd-5.87 PFBS: nd- 0.12 PFHxS: nd- 0.07 PFOA: nd- **1.80** α-HCH: nd-0.20 β-HCH: nd- 0.42	Schecter et al. (2010a)
USA	Meat, fish, dairy, cheese and vegetables (ng/g, ww)	HBCD: nd-0.593 PBDEs: 11.1–6.194	Schecter et al. (2010b)
Cameroon	dried foods (ng/g)		

(continued on next page)

Table 4 (*continued*)

Country	Food	Concentration	Author
		Aldrin: 1.2–464.6 Dieldrin: 1.2–60.4 Endrin: 1.2–33.7 Heptachlor: 1.2–123.6 Malathion: 7.3–5526.9 o,p'-DDT: 1.3–15.6 p,p'-DDD: 1.2–24.1 p,p'-DDE: 1.3–27.6 p,p'-DDT: 3.3–146.6 α-Endosulfan: 1.2–41.5 β-endosulfan: 1.7–1.7 β-HCH: 1.2–137.1	Galani et al. (2018)
Canada	Composite food Samples from TDS (ng/g, ww)	PFNA[H]: <1 and 4.5 PFOA: <0.5-**3.6**, PFOS: <0.6-**2.7**	Ronson et al. (2007)
Portugal	Duplicate Diet (ng/g ww)	CHLs: <LOD-1 DDTs: 0.11–0.73 HBCDDs[I]: <LOD-1.2 HCB: <LOD-0.062 HCHs: 0.0093–0.16 PBDEs: <LOD-0.23 PCBs: <LOD-0.95	Coelho et al. (2016)

Numbers in bold font exceed the regulatory limit for biodegradable waste.
A: Perfluorinated carboxylic acid, B: Perfluorinated sulfonates, C: Hexachlorobenzene, D: Chlordanes, E: Hexachlorocyclohexane, F: Perfluorobenzoic, G: Perfluorohexanesulfonate, H Perfluorononanoate, I: Hexabromocyclododecane and J: Method limit of quantification.

from US rivers (production stage) (Batt et al., 2017). Perfluorooctanesulfonic acid (PFOS) (66.3 ng/g ww) was also detected at high concentrations in fish collected from South Carolina (USA) (Fair et al., 2019). PFOA (8 ng/g ww) was highest in fish collected from the Sava river basin, which touches six European countries' territories (Ábalos et al., 2019). All these fish samples were taken from areas with high industrial activity, areas with chemical industries, high pesticide application rates and discharge from wastewater treatment plants. These sources might be discharging halogenated compounds into the rivers where they bioaccumulate in fish. Wastes from foods with Organohalogen contamination can intensify the probability of accumulation in compost/digestate and represent a risk to a circular food system.

Maine, a northern state in the US, has implemented PFAS regulatory limits for biosolids application (PFOA: 2.5 ng/g dw, PFOS: 5.2 ng/g dw and Perflurobutanesulfonoic acid (PFBS): 1900 ng/g dw) (DEP, 2019). The Luxembourg limit of 100 ng/g dw PCBs and Maine regulatory limits are used to compare PCBs and PFASs in food respectively. Any values for PCBs and PFASs in Table 4 that exceeded these levels are reported bold. Assumptions for weight reporting and conversion from wet weight to dry weight were as described for heavy metals.

2.3. Pathogens

Foodborne illness can be acquired through ingestion of foodborne pathogens, or ingestion of toxins produced by toxigenic pathogens in food products (Bintsis, 2017). *Salmonella* and pathogenic *E. coli* are the top foodborne pathogens worldwide, although they produce more infections in Asia and Africa than elsewhere (Fegan and Jenson, 2018). The US Center for Disease Control (CDC) estimates that one in six Americans (i.e. 48 million) suffer from foodborne illness each year (Hoagland et al., 2018). Once a food source has become contaminated, outbreaks occur rapidly, infecting many people (Hoagland et al., 2018). There were 839 documented food-related outbreaks in 2017 in the US, resulting in 14,471 reported cases of illness, 822 hospitalizations and 21 deaths (NORS CDC, 2019). *Norovirus*, *Salmonella*, *Campylobacter*, *Bacillus*, and *E. coli* (pathogenic) are some of the foodborne pathogens responsible for those outbreaks, illnesses, hospitalizations and deaths. In 2017, *norovirus* infections caused more outbreaks, illnesses and hospitalizations than the other pathogens, however, *Salmonella* was responsible for a greater number of deaths. The types of food responsible for causing illnesses, hospitalizations and deaths were found to be meat, poultry, dairy, fruits, vegetables, seafood, grains, and nuts. Although the literature shows a low prevalence of food-borne pathogens in food in the US, the data in Table 5 shows that the consequences of exposure through food can be severe, and a sizeable number of people are affected annually.

2.3.1. Sources of pathogens in food

Sources of pathogen contamination of fresh produce at the farm level include livestock and human movement, land-application of raw manure, contaminated irrigation water, immature compost application, contaminated soil, and runoff from compost and manure stockpiles on the farm (Bilung et al., 2018; Ceuppens et al., 2014; Ssemanda et al., 2018). Produce leaves that touch the ground are more prone to pathogenic contamination than plants whose leaves have not (Reddy et al., 2016). Water distribution systems such as surface furrow and drip irrigation system pose less risk than sprinkler systems because the latter irrigation water comes in contact with the edible portion of the plants (Alegbeleye et al., 2018). Fecal contamination was identified as the primary source of milk contamination at farms (Del Collo et al., 2017; Mcauley et al., 2014).

Processing steps are often found to be more susceptible to pathogen contamination than production steps (Heredia et al., 2016; Ilic et al., 2008; Johnston et al., 2005; Perez-Arnedo and Gonzalez-Fandos, 2019). Environmental samples (soil, feces, water), poorly sanitized food contact surfaces (conveyor belt, knives, slices etc.) and poorly sanitized non-food contact surfaces (walls, drains, floors etc.), unhygienic design of plants, unregulated traffic patterns, non-sanitized worker's hands, transport trailers and crates are some of the sources of contamination (Heredia et al., 2016; Johnston et al., 2006; K. Li et al., 2017; Muhterem-Uyar et al., 2015; Perez-Arnedo and Gonzalez-Fandos, 2019). High contamination in meat processing plants (probably due to cross contamination from animal carcasses) and cutting and packaging rooms may be due to unhygienic design of bleeding, plucking and evisceration equipment (Muhterem-Uyar et al., 2015; Perez-Arnedo and Gonzalez-Fandos, 2019). Cross contamination with foodborne pathogens can occur during transportation or while animals are waiting in lairage before slaughter (Carrasco, Morales-rueda, & García-gimeno, 2012; Larsen et al., 2014). Biofilms (thin slime layers of bacteria) are the major vehicle for microbial food contamination (Ripolles-avila, Hascoët, Martínez-suárez, Capita, & Rodríguez-jerez, 2019).

At the retail stage, observed food contamination may originate at the retail site or from previous stages in the food supply (production and processing) as shown in a study by Dickins et al. (2016). Shelf life, packaging materials and style, rodents and refrigeration systems are some of the factors which need to be taken into consideration for

Table 5
Outbreak data due to foodborne pathogens in US in 2017.

Pathogens	Outbreaks	Illness	Hospitalized	Death
Bacillus	25	704	56	2
Campylobacter	27	770	117	1
Clostridium	57	1480	64	3
E. coli	27	770	117	1
Listeria	7	28	27	3
Norovirus	318	6389	54	4
Salmonella	125	3228	528	9
Shigella	4	54	10	0
Staphylococcus	22	559	56	2
Streptococcus	1	62	0	0
Vibrio	20	91	5	0

(NORS, CDC, 2019)

prevention of further contamination (Sharma et al., 2019; Trimoulinard et al., 2017). Various field management techniques, poor regulatory guidance, emphasis on minimal application of antibiotics and interest in organic processes could be some of the reasons for the high prevalence of pathogens in produce collected from a farmer's market in West Virginia, USA (K. Li et al., 2017). When food with foodborne pathogens is prepared for consumption, kitchen surfaces and implements can transfer pathogens from one food to another, causing cross contamination (Mol et al., 2018; Redmond and Griffith, 2003).

Various studies have demonstrated that fresh produce has a low incidence of foodborne pathogens as shown in Table 6 (Denis et al., 2016; Mukherjee, Speh, Jones, Buesing, & Diez-gonzalez, 2006; Seow et al., 2012). This can be attributed to stringent regulation and enforcement of food and produce safety protocols. In a study by Luchansky et al.,(2017), *L. monocytogenes* decreased over time following changes in industrial and regulatory practice prompted by improved knowledge of the biology and ecology of the pathogen since the first outbreaks in the early 1980s (Cheruiyot et al., 2016).

Table 6 shows the extreme variability in incidence of foodborne pathogens in different foods from around the world. The highest incidences of *Salmonella* (16.03%) (K. Li et al., 2017) and *Campylobacter* (82%) (Dickins et al., 2002) in the studies reviewed here occurred at the retail stage. The highest prevalence of *L. monocytogenes* (up to 26.19%) (Muhterem-Uyar et al., 2015) was at the processing stage, whereas shiga-toxigenic *Escherichia. coli* (STEC) (33%) (Sonnier et al., 2018) was most prevalent in samples taken from the production stage. Poorly sanitized food contact and non-food contact surfaces, unhygienic processing plants and cross contamination were the reasons proposed for the high prevalence of *L. monocytogenes* (Muhterem-Uyar et al., 2015). Lack of use of antimicrobials in the post-harvest control process in organic fresh produce was suspected to contribute to the higher prevalence of *Salmonella* at farmers' markets than in conventional supermarket samples (K. Li et al., 2017). Contamination at the brooder house or in the post-slaughter stages were suspected to be the possible reasons for the high prevalence of *Campylobacter* in chicken (Dickins et al., 2002). The possibility of pathogen contamination of food, and subsequently in food waste, could raise the incidence of pathogens in the final product after food waste treatment.

2.4. Antibiotic resistance genes (ARGs)

Antibiotics are used in agriculture for disease treatment and prevention, and for non-medicinal purposes, as feed proficiency enhancers and growth promoters (Bengtsson-Palme Johan, 2017; Van et al., 2019). ARGs are genes that confer antibiotic resistance. They may be encoded in the genome or on mobile genetic elements (MGE). They can be acquired by mutation, uptake from the environment (transformation), direct transfer from another organisms (conjugation), or transfer by viral infection (transduction) (Jose L. Martinez, Baquero and Anderson, 2007).

More antibiotics are currently used in the animal production sector than in the human health sector in Europe and USA (Caniça et al., 2019). Antibiotics are also used to protect plants from diseases, although much less than in animal rearing (Bengtsson-Palme Johan, 2017; Hudson et al., 2017). There are connections between antibiotic use in agricultural production and resistance among human pathogens, with food being the transferring vector (Verraes et al., 2013). Regular, low-level antibiotic use in densely packed food animals exerts selective pressure favoring resistant bacteria, resulting in the evolution of novel resistant strains (Koch et al., 2017). ARGs can be disseminated among microorganisms, including pathogens, through horizontal gene transfer (HGT), which is the movement of genetic materials between cells (Lau et al., 2017). Antibiotic resistant human pathogens can cause failure of current human therapies (Verraes et al., 2013). The CDC estimates that in the US, antibiotic resistant infections affect a minimum of two million people annually, resulting in 23,000 deaths (Pepper et al., 2018).

Colistin is a last resort antibiotic used to treat human infections caused by clinically resistant gram-negative bacteria such as carbapenem-resistant Enterobacteriaceae (Y.-Y. Liu et al., 2016). This means that colistin is a last-line treatment option against multidrug resistant gram negative Enterobacteriaceae. In 2015, a bacterium with plasmid-mediated colistin resistance conferred by the *mcr-1* gene was isolated from animals, raw meats and patients in China. Since then, additional varieties of colistin resistance genes, namely *mcr-2 - mcr-9,* have been detected worldwide (Van et al., 2019). This is putting the human healthcare system at risk.

2.4.1. Sources of ARGs in food

There are several reports of the association between the use of antibiotics in food-producing animals and antibiotic resistance in bacteria isolated from humans (Martinez, 2009). The use of antibiotics in livestock is associated with the emergence of antibiotic resistance in food-borne pathogens and livestock bacteria (Zwe et al., 2018). Multidrug resistant *Salmonella, Escherichia coli (E. coli), Campylobacter* and other foodborne pathogens and opportunistic pathogens have been isolated from food -producing animals and fresh produce at different stages of the food system in recent years (Bosilevac et al., 2009; Del Collo et al., 2017; Holvoet et al., 2013; Karumathil, Yin, Kollanoor-johny, & Venkitanarayanan, 2016; S. Liu & Kilonzo-nthenge, 2017; Schwaiger et al., 2011; Sivagami et al., 2018; Sjölund-Karlsson et al., 2013; Zwe et al., 2018). These microbes were resistant to azithromycin, tetracycline, nalidixic acid, amikacin, ciprofloxacin, trimethoprim-sulfamethoxazole and cephalosporin (Bosilevac et al., 2009; Sjölund-Karlsson et al., 2013). Antibiotic-resistance genes such as ceftriaxone-, aminoglycoside-, beta-lactam (*bla*)-, chloramphenicol-, sulfamethoxazole-, tetracycline (*tet*)-, and trimethoprim-resistance genes have all been detected in *Salmonella* (Iwamoto et al., 2017; Sjölund-Karlsson et al., 2013).

In the processing environment, contaminated surfaces can be a source for the transfer of ARGs, as shown in a Malaysian market study (Hudson et al., 2017). Bacteria on contaminated surfaces take up genetic materials and become resistant. At a new chicken farm, antibiotic-resistance genes were detected in litter samples after the arrival of the flock, but not before. The operators denied using antibiotics, which indicates either the amplification of resistance genes already in the environment or introduction with the broiler chicks as the carrier from their previous environment (Brooks et al., 2016). This shows that ARGs can spread resistance in the inter-connected environment.

Techniques to kill or inactivate microbial populations such as the use of preservatives, temperature, or salt may be used during processing. These methods create stress in the microbes leading to the inactivation of many. However the same processes can also stimulate the transfer of ARGs among microbes with prolonged exposure to such stresses (Perez-Rodriguez and Taban, 2019).

Cross-contamination is likely to occur during transport of food and in the processing environment. Antibiotic-resistant *Salmonella* have been isolated from the environment where animals are held prior to slaughter. These lairage areas then act as a contamination source, passing resistant organisms to subsequent groups of animals on their way to slaughter (Hudson et al., 2017).

Tetracycline-resistance genes are frequently detected in food and foodborne bacteria (Sharma et al., 2019; Xiong et al., 2019). In these studies, there was a difference between the ARGs detected in land-based agriculture and aquatic food products, probably due to differences in microbial communities, and environmental structure. Xiong et el. (2019) found that the same ARGs that dominated in swine manure were most commonly detected in fresh produce from the area (*tet*(M), *aadA* and *qacE*), however they lacked the evidence to state definitively that the swine manure was the source of the ARGs (Xiong et al., 2019).

Misuse of antibiotics for growth promotion and disease prevention has triggered multi drug resistance in foodborne pathogens (Sharma

Table 6
Occurrence of foodborne pathogens in food from different countries at different stages of the food supply chain.

Country	Food	Foodborne Pathogen data (Value)	Author
Production Stage			
USA	Milk	Filter: *E. coli*: 216/254 *L. monocytogenes*: 14/254 *Listeria* spp.: 47/254 *Salmonella*: 61/254 Bulk Tank Milk (BTM): *E. coli*: 77/234 *L. monocytogenes*: 4/234 *Listeria* spp.: 6/234 *Salmonella*: 11/234	Sonnier et al. (2018)
USA	Milk	Filter: *Campylobacter*: 69/231 BTM: *Campylobacter*: 27/234	Del Collo et al. (2017)
USA	leafy green samples	*E. coli*: 2/369 *Salmonella*: 15/369	Marine et al. (2015)
USA	Fruits and vegetables	*Salmonella* and *E. coli* not detected in food out of 2029 fruits and vegetables	Mukherjee et al. (2006)
USA	Produce mostly eaten raw	*Salmonella*: 3/398 (only in cantaloupe) *L. monocytogenes* and Pathogenic *E. coli*: not detected in food	Johnston et al. (2005)
Australia	Milk	raw milk: *E. coli:* 1/15 *Salmonella*: 1/15 *Campylobacter* and *Listeria* spp.: not detected in food Milk filter: *Listeria*: 1/9 *Salmonella*: 2/9 *Campylobacter* and *STEC*: not detected in food	Mcauley et al. (2014)
Malaysia	Vegetables	*Listeria* spp.: 9/206 *L. monocytogenes*: not detected in food	Bilung et al. (2018)
Processing Stage			
USA	18 beef processing industries	*Salmonella*: 172/4136	Bosilevac et al. (2009)
USA	Ground beef	*Salmonella*: 30/370	Vikram et al. (2018)
USA	Spinach	*E. coli*: 0/1356 *L. monocytogenes*: 3/409 *Listeria* spp. 5/409 *Salmonella*: 1/404 (before processing) *Salmonella*: 4/907 (after processing), *Shigella*: 0/1311	Ilic et al. (2008)
Ireland	Food processing facilities	*L. monocytogenes*: 22/432	Leong, Alvarez-ordóñez, & Jordan (2014)
Six European Countries	Food processing industries	*L. monocytogenes*: Meat: 22/84 Dairy: 40/1362	Muhterem-Uyar et al. (2015)
Retail Stage			
USA	Meat	*Campylobacter*: 159/719 *E. coli*: 179/825 *Salmonella*: 25/825	(C. Zhao et al., 2001)
USA	Retail meat	*Campylobacter*:3190/24566	(S. Zhao et al., 2010)
USA	Chicken	*Campylobacter*: 59/72	Dickins et al. (2002)
USA	Vegetables	*E. Coli*: 1/414 *L. monocytogenes*: 1/414 *Salmonella*: 2/414	Cheruiyot et al. (2016)
USA	Fresh produce	*L. monocytogenes*: 4/212 *Listeria* spp.: 8/212 *Salmonella*: 34/212	(K. Li et al., 2017)
USA	Fresh produce	*Salmonella:* 456/111598 (PCR positive), 146/456 isolates from PCR positive samples	Reddy et al. (2016)
USA	Ready to eat (RTE)	*L. monocytogenes*: 116/27389	Luchansky et al. (2017)
Canada	Fruits and vegetables	*Campylobacter*: 0/8866 *E. coli*: 0/23805 *L. monocytogenes*: 16/4575 *Salmonella*: 10/29391	Denis et al. (2016)
China	RTE meat products	*E. coli*: 40/3774 *L. monocytogenes*: 57/3974 *S. Aureus*: 32/4047 *Salmonella*: 26/4035	Yang et al. (2016)
Czech Republic	Fruits and vegetables	*L. monocytogenes*: 17/339 *Salmonella*: 1/339	(Panel HanaVojkovská et al., 2017)
India	Meat	*Salmonella*: 28/188	Sharma et al. (2019)
India	Meat	*E. coli*: 3/480 *L. monocytogenes*: 14/480 *Salmonella*: 16/480	Mritunjay & Kumar (2017)

(*continued on next page*)

Table 6 (*continued*)

Country	Food	Foodborne Pathogen data (Value)	Author
Reunion Island, Africa	Sausages	*Campylobacter*: 3/203 *L. monocytogenes*: 12/203 *Listeria* spp.: 61/203 *Salmonella*: 24/203	Trimoulinard et al. (2017)
Singapore	Vegetables and fruits	*Salmonella*: 0/125	Seow et al. (2012)
Wales, UK	RTE	*Campylobacter*: 0/2061 *L. monocytogenes*: 58/15228 *Salmonella*: 1/15228	Meldrum et al. (2005)

E. coli mentioned in the Table 6 is pathogenic *E. coli*.

et al., 2019). Colistin is widely used as a growth promoter in livestock in some parts of the world (Ghafur et al., 2019; Monte et al., 2017). Colistin-resistance genes are spreading widely throughout the environment. *Mcr-1* and *mcr-2* have been detected in pork carcasses, chicken meat and mutton in Belgium, Brazil and India respectively (Garcia--graells et al., 2018; Ghafur et al., 2019; Monte et al., 2017). In contrast, none of the 1000 STEC isolates collected from 2006 through 2014 from livestock, wildlife, produce, soil and water samples from a major food-producing region of California, tested positive for *mcr-1* or *mcr-2* (Mavrici et al., 2017). Colistin has been widely used as a growth promoter in Belgium, India, China and Brazil, but not in the US (Sun et al., 2017), which could account for the detection of colistin resistance genes in those countries.

The literature review on pathogens in food indicates that they are not very common or abundant in food. This means that ARGs are more likely to reside in non-pathogenic microbes than pathogenic microbes in the food chain supply. It is not easy to track the survival rates of the antibiotic-resistant population, but there is a high likelihood that once they get into the food system, they will stay there, grow and they will be detectable in raw food or ready to eat food (Perez-Rodriguez and Taban, 2019).Table 7 shows the prevalence of ARGs in different food, especially in pathogens isolated from food, collected from different countries at production, processing and retail stages of the food system. The majority of studies report on foodborne pathogens that are resistant to antibiotics or contain ARGs as opposed to the overall abundance of ARGs in food, which would provide information on the background abundance of these genes. On comparing beta-lactam resistance genes between the food system stages, bla_{TEM} was detected in a maximum of 57% of the isolates at the processing stage (Glenn et al., 2013), and bla_{CMY} was present in 92% of isolates cultured from samples at the retail stage (Sharma et al., 2019). Furthermore, many of the isolates obtained from the food are resistant to more than one antibiotic or have more than one resistance gene i.e. multi drug resistance (MDR). Wide use of antibiotics in agriculture and detection of ARGs in food means they will be present in food waste intended for recycling.

3. Fate of contaminants in compost and digestate

Food waste can be contaminated due to contamination introduced at each stage of the system as described above, poor source separation may introduce materials associated with food consumption, like food packaging, plastics, toothpicks, paper towel and so on, or contaminants may be introduced by poor separation following mixed waste collection (Chu et al., 2019). Source separated food waste collection system is generally recommended to reduce the risk of contamination in a circularized system (Amlinger et al., 2004). Some contaminants can also be transformed during treatment prior to reuse of the residuals.

Heavy metals are recalcitrant and do not degrade in food waste treatment systems such as composting or anaerobic digestion (Lin et al., 2018). The concentration of heavy metals will increase due to microbial degradation and loss of carbon and water from the compost (Farrell and Jones, 2009). Metal bioavailability decreases with the length of composting due to binding of metals by complexation and sorption with organic matter, microbial immobilization and oxidation (Farrell and Jones, 2009). As the compost matures, humic materials in compost tend to increase, resulting in greater binding capacity and lower bioavailability of metals (Hargreaves et al., 2008). Heavy metals in source-separated digestates were lower than in compost due to less loss of organics in digestates (Kupper et al., 2014).

Amlinger et al. (2004) found that most organochlorine compound concentrations are higher in their feedstocks than in finished compost. S. R. Smith (2009) has pointed out the efficacy of aerobic processes in removing organic contaminants over anaerobic processes due to the greater range of metabolic pathways available under aerobic conditions. Thermophilic temperature seems to be effective in removing volatile compounds while microbial reactions are effective at removing labile compounds. The maturation phase in composting can immobilize some recalcitrant POPs. POPs become bound to organic matter, at least in the short term, reducing their bioavailability (Farrell and Jones, 2009). PCBs have been widely studied in compost and digestate. In an experiment on degradation of PCBs in compost by Brandli et al. (2007), there was no reduction in total PCBs, but there was a shift from high molecular weight to lower molecular weight congeners. Four main processes; evaporation, sequestration, transformation and contamination are responsible for influencing PCBs levels and it is difficult to distinguish their effects (Brandli et al., 2007). Siebielska & Sidełko (2015) stated that more highly chlorinated PCBs had higher degradation rates due to dechlorination by microbes. In their study, they found anaerobic treatment was more efficient in degrading PCBs than composting. Aerobic oxidation processes are more effective at removing less-chlorinated PCBs than more chlorinated congeners (Siebielska and Sidełko, 2015). Poor bioavailability of some halogenated compounds can limit their susceptibility to dehalogenation (Stasinakis, 2012). Although defluorination is thermodynamically possible and could produce sufficient energy to support microbial growth, research has shown fluorinated compounds to be stable. Poor defluorination and biodegradation of PFASs is probably due to the strength of C–F bond resulting very slow reaction kinetics (Stasinakis, 2012).

Microbial composition/host bacteria, physicochemical properties like pH, operational parameters, selective pressure from antibiotics and metals, retention time or composting stage, were seen as some of the parameters that determine the fate of ARGs in composting and anaerobic digestion (Ezzariai et al., 2018; Liao et al., 2019; Oliver et al., 2020; Zhang et al., 2016). ARGs harbored by bacterial cells tend to amplify with time due to cell growth and HGT, but can be attenuated via differential survival in response to treatment conditions (Ma et al., 2011). ARGs were seen to be positively related with the abundance of potential bacterial hosts (Ma et al., 2011; Tang et al., 2020) and declined during maturation of compost due to a decline in the bacterial population. Thus, aging compost can serve as a way to control ARGs (Tang et al., 2020). Thermophilic composting and anaerobic digestion (>55 °C) conditions were better at reducing ARGs than lower temperature operations (H. Li, Cheng, Li, Xu and Zheng, 2020; Oliver et al., 2020; Shin et al., 2020). Mesophilic operation is especially prone to produce stable or increasing abundance of ARGs (Ma et al., 2011). Higher temperature offers the benefit of limited bacterial hosts for acquisition of ARGs and enhanced biological and chemical reaction rates (Ma et al., 2011). ARGs associated with MGEs were difficult to remove in industrial composting

Table 7
Occurrence of ARGs in food at different stages of food supply chain.

Country	Food	ARGs
Production Stage		
USA[a]	Milk	41 *Campylobacter* spp. (38 *C.jejuni*. 2 *C. coli* and 1 *C. coli*) was subjected to 9 common antimicrobial testing. 26/38 (68.4%) *C. jejuni* were resistant to tetracycline, 5/38 (13.2%) was resistant to both ciprofloxacin and nalidixic acid. 12 *C.jejuni* isolates were susceptible to all 9 antimicrobials testing. *C. lari* was resistant to ciprofloxacin and nalidixic acid. *C.coli* was resistant to all the tested 9 antimicrobial substances.
USA[b]	Fruits and vegetables	None of the samples yielded any positive samples for colistin resistant gene
Germany[c]	Farm (299) and supermarket (702)	number of samples from farm had showed more resistance than the supermarket samples
Nigeria[d]	Food animals	Measured in *E. coli* isolates: bla_{TEM}: 54/211, bla_{CMY}: 126/211, bla_{CTX}: 6/211, bla_{OXA}: 2/211, bla_{SHV}: 0
Spain[e]	Fresh produce (ARGs screened in the phage extract	9 ARGs in upto 75% of lettuce, 6 ARGs in upto 82% soil samples, 4 ARGs in upto 69% cucumber and 3 ARGs in upto 27% spinach. The most abundant group was $bla_{CTX\text{-}M\text{-}9}$, bla_{TEM} and bla_{VIM} …
Processing Stage		
USA[f]	*Salmonella* isolates from slaughterhouse and processing plants	Ceftriaxone resistance *Salmonella* detected in 1576 (9.5%) of 16,608 *Salmonella* isolates from chicken, 248 (5.6%) of 4457 isolates from turkey and 1192 (12.6%) of 9461 isolates from cattle.
USA[g]	Ground beef processing	0.6% MDR *Salmonella* isolates resisted from 2 to 10 tested antibiotics including tetracycline
USA and Canada[h]	Slaughterhouse and retail *Salmonella* isolate along with patients	*Tet*(A): 45/56, *tet*(B): 8/56, *tet*(C): 8/56, *tet*(D): 7/56, *tet(R)*: 50/56, bla_{TEM}: 32/56, bla_{CMY}: 30/56, bla_{PSE}: 36/56.
USA[i]	Ground beef samples	*Tet*(M): 64/75, Relative Abundance: 10^{-5}-1 (values not accurate, extracted from graph) *Tet*(B): 10/75, Relative Abundance: $<10^{-5}$->10^{-4}(values not accurate, extracted from graph) *Tet*(A): 29/75, Relative Abundance: $>10^{-4}$-<1(values not accurate, extracted from graph)
Canada[j]	26 pathogenic *E. coli* obtained from commercial ground beef	Polymerase Chain Reaction (PCR) confirmation: *tet*(A)-1/26, *tet*(B)-9/26, *tet*(C)- 5/26, bla_{CMY}-5/26, and bla_{TEM}- 11/26
India[k]	Processing and retail shop (the shops processed and sold the meat)	Measured in total *Salmonella* isolates: *tet*(A): 70/70, *tet*(B): 0/70, *tet*(G): 0/70, bla_{TEM}: 17/67, $bla_{PSE\text{-}1}$:1/67, bla_{CMY}: 1/67
Retail Stage		
USA and Canada[l]	Retail meat, ceca and food animals	USA bla_{CMY}: retail: 57/77, food animals: 138/140 isolates $bla_{TEM\text{-}1}$: retail meat: 8/77, food animals: 15/140 Canada bla_{CMY}: retail meat: 48/52, food animals: 28/42, $bla_{TEM\text{-}1}$: retail meat: 1/52, food animals: 2/42
Belgium[m]	*Salmonella* from different foods	32/398 in 2012, 18/296 in 2013, 38/294 in 2014 and 17/427 in 2015 were found to be colistin resistant. Total: 105/1415 *mcr-1*: 2/105 *mcr-2*: 1/105 *mcr-1* and *mcr-2* was found in pork carcasses in 2012. The other one was the poultry samples
Brazil[n]	Chicken	*mcr-1*:8/41
China[o]	Rectal from pig slaughterhouse and retail meat	Colistin resistant *E. coli* isolates Slaughter: 166/804 (21%) Retail Meat: 78/523, (15%) First report of plasmid mediated colistin resistance mechanism in animals
India[p]	*E. coli* from raw meat, vegetables from shops and households	Colistin resistant organisms: vegetables: 23/63, fish samples: 11/21, poultry samples: 12/19, mutton: 3/4 and fruits: 2/3 PCR screening showed that 3/71 *E. coli* harbored *mcr-1* gene (1 mutton and 2 poultry meat samples)

[a] = (Del Collo et al., 2017)
[b] = (Mavrici et al., 2017)
[c] = (Schwaiger et al., 2011)
[d] = (Adenipekun et al., 2019),
[e] = (Larrañaga et al., 2018)
[f] = (Iwamoto et al., 2017)
[g] = (Bosilevac et al., 2009)
[h] = (Glenn et al., 2013)
[i] = (Vikram et al., 2018)
[j] = (Aslam et al., 2009)
[k] = (Sharma et al., 2019)
[l] = (Sjölund-Karlsson et al., 2013)
[m] = (Garcia-graells et al., 2018)
[n] = (Monte et al., 2017)
[o] = (Y.-Y. Liu et al., 2016) and
[p] = (Ghafur et al., 2019).

settings as ARGs on MGEs can spread through HGT (Tang et al., 2020). Thus, MGEs are found to be a significant contributing factor for determining the fate of ARGs in the treatment system (Tang et al., 2020; Zhang et al., 2016). ARGs have thus been shown to decrease or increase in the final products compared to their initial abundance (Ezzariai et al., 2018; Ma et al., 2011). With limited and conflicting information available on ARG transfer and the associated threat of application of contaminated compost to soil (Ezzariai et al., 2018), the fate of ARGs remains unclear and there is an immediate need to determine optimal treatment parameters.

Thermophilic temperature more effectively inactivates pathogens in digestate and compost (Gurtler et al., 2018; Jiang et al., 2020), however thermophilic AD operation requires more energy and expense. Microbial metabolism generates thermophilic temperatures during composting (Gurtler et al., 2018). Thus, good conditions for microbial growth should be ensured. Volatile organic acids and ammonia released during treatment can also inactivate pathogens in digestate and compost (Gurtler et al., 2018; Jiang et al., 2020). Treatment configuration, pH, competition between microbes, nutrient availability, carbon nitrogen ratio and initial pathogen number are some of the factors that need to be optimized for pathogen inactivation in digestate and compost (Gurtler et al., 2018; Jiang et al., 2020; Orzi et al., 2015). Pasteurization of digestate is recommended in the case of mesophilic AD (Jiang et al., 2020). Turning compost to ensure that all the material is exposed to high heat is necessary (Gurtler et al., 2018).

There is limited information on the fate of organic compounds and ARGs in compost and digestate from food waste. Failure to maintain appropriate operational conditions in AD/compost can result in the accumulation of contaminants in the final products. Repeated land

application of such contaminated products can result in the accumulation of contaminants in the soil and uptake by plants. The best way to avoid contamination of the final product is to maintain clean feedstock materials. Safe recycling practices, such as careful source separation of food waste, can help to generate high quality inputs resulting in desirable, and marketable, end products that are suitable for a circular food system.

4. Conclusion

The above review presents the sources of several classes of contaminants that can enter our food system. Each stage of the food system has unique contamination sources and mechanisms. Our review of the available literature produced the following insights:

1. Heavy metals were largely introduced at the production stage, although processing and packaging were also significant sources of some metals for some foods. Metals can persist and increase in concentration in the final products from treatment systems, while their mobility decreases.
2. For halogenated organics, the production stage produced the highest level of contamination for PCBs, PBDEs, DDT, PFOA and PFOS. Some may also be introduced in packaging and from food contact papers. Many persist in the final products of the treatment system. While the diversity of this class of contaminants and differences in chemical properties prevent broad generalizations about their fate during processing and treatment, the potential for many of these compounds to persist and bioaccumulate inherently represents a risk to any food system.
3. ARGs are mostly introduced during animal rearing as a result of non-therapeutic antibiotic use and may contaminate meat during processing or vegetables during production. The fate of ARGs during treatment is inconsistent and more research is needed to determine conditions that result in their persistence and destruction.
4. Pathogens are largely introduced during the processing stage for meat products, and the production stage for vegetables. Handling at retail and consumer sites can also introduce pathogens. Thermophilic temperatures effectively kill pathogens during treatment. However, high temperatures must be reached throughout the compost pile, and operation of AD systems in this temperature range can be unstable.

Repeated land application of treated food waste residuals can result in accumulation of contaminants if they are present in the feedstocks. Contaminants can be taken up by plants and accumulate in a circular food system, jeopardizing its safety. Thus, contamination at any stage represents a threat to the system as a whole. To maintain a sustainable circular food system, careful management of the system is needed to reduce the level and frequency of contamination of food, and research into the fate of contaminants during treatment, methods for simple, inexpensive and accurate monitoring, and policy options to protect the system are needed.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

This work is supported by Environment Research and Education Foundation (EREF), USA.

REFRENCES

Ábalos, M., Barceló, D., Parera, J., Farre, M. la, Llorca, M., Eljarrat, E., Abad, E., 2019. Levels of regulated POPs in fish samples from the Sava River Basin . Comparison to legislated quality standard values. Sci. Total Environ. 647, 20–28. https://doi.org/10.1016/j.scitotenv.2018.07.371.

Abbas, M., Chand, N., Khan, R.U., Ahmad, N., Pervez, U., Naz, S., 2019. Public health risk of heavy metal residues in meat and edible organs of broiler in an intensive production system of a region in Pakistan. Environ. Sci. Pollut. Control Ser. 26, 23002–23009.

Adenipekun, E.O., Jackson, C.R., Ramadan, H., Iwalokun, B.A., Frye, J.G., Barrett, J.B., Oluwadun, A., 2019. Plasmid replicons and b -lactamase-encoding genes and food animals in Lagos , southwest Nigeria. Microb. Drug Resist. https://doi.org/10.1089/mdr.2018.0305.

Ahrens, L., Bundschuh, M., 2014. Fate and effects of poly-and perfluoroalkyl substances in the aquatic environment: a review. Environ. Toxicol. Chem. 33 (9), 1921–1929. https://doi.org/10.1002/etc.2663.

Alegbeleye, O.O., Singleton, I., Sant'Ana, A.S., 2018. Sources and contamination routes of microbial pathogens to fresh produce during field cultivation: a review. Food Microbiol. 73, 177–208. https://doi.org/10.1016/j.fm.2018.01.003.

Alharbi, O.M.L., Basheer, A. Al, Khattab, R.A., Ali, I., 2018. Health and environmental effects of persistent organic pollutants. J. Mol. Liq. 263, 442–453. https://doi.org/10.1016/j.molliq.2018.05.029.

Amlinger, F., Pollack, M., Favoino, E., 2004. Heavy metals and organic compounds from wastes used as organic fertilisers. Study on the Behalf of European Commission, Directorate-General Environment, ENV. A 2 (July), 1–244.

Aslam, M., Diarra, M.S., Service, C., Rempel, H., 2009. Antimicrobial resistance genes in Escherichia coli isolates recovered from a commercial beef processing plant †. J. Food Protect. 72 (5), 1089–1093.

Babu, G.S., Farooq, M., Ray, R.S., Joshi, P.C., Viswanathan, P.N., Hans, R.K., 2002. DDT and HCH residues in basmati rice (oryza sativa) cultivated in dehradun (India). *Water, air*. Soil Pollution 144, 149–157.

Batt, A.L., Wathen, J.B., Lazorchak, J.M., Olsen, A.R., Kincaid, T.M., 2017. Statistical survey of persistent organic pollutants: risk estimations to humans and wildlife through consumption of fish from U.S. rivers. Environ. Sci. Technol. 51 (5), 3021–3031. https://doi.org/10.1021/acs.est.6b05162.

Bilung, L.M., Chai, L.S., Tahar, A.S., Ted, C.K., Apun, K., 2018. Prevalence, genetic heterogeneity, and antibiotic resistance profile of Listeria spp . and Listeria monocytogenes at farm level : a highlight of ERIC- and BOX-PCR to reveal genetic diversity. BioMed Res. Int. *2018*.

Bintsis, T., 2017. Foodborne pathogens. AIMS Microbiology 3 (June), 529–563. https://doi.org/10.3934/microbiol.2017.3.529.

Blocksom, K.A., Walters, D.M., Jicha, T.M., Lazorchak, J.M., Angradi, T.R., Bolgrien, D. W., 2010. Persistent organic pollutants in fish tissue in the mid-continental great rivers of the United States. Sci. Total Environ. 408, 1180–1189. https://doi.org/10.1016/j.scitotenv.2009.11.040.

Bortey-sam, N., Nakayama, S.M.M., Ikenaka, Y., Akoto, O., Baidoo, E., Beyene, Y., Ishizuka, M., 2015. Human health risks from metals and metalloid via consumption of food animals near gold mines in Tarkwa , Ghana : estimation of the daily intakes and target hazard quotients (THQs). Ecotoxicol. Environ. Saf. 111, 160–167. https://doi.org/10.1016/j.ecoenv.2014.09.008.

Bosilevac, J.M., Guerini, M.N., Kalchayanand, N., Koohmaraie, M., 2009. Prevalence and characterization of salmonellae in commercial ground beef in the United States. Appl. Environ. Microbiol. 75 (7), 1892–1900. https://doi.org/10.1128/AEM.02530-08.

Brandli, R.C., Bucheli, T.D., Kupper, T., Mayer, J., Stadelmann, F.X., Tarradellas, J., 2007. Fate of PCBs , PAHs and their source characteristic ratios during composting and digestion of source-separated organic waste in full-scale plants. Environ. Pollut. 148, 520–528. https://doi.org/10.1016/j.envpol.2006.11.021.

Brooks, J.P., McLaughlin, M.R., Adeli, A., Miles, D.M., 2016. Cultivation and qPCR detection of pathogenic and antibiotic- resistant bacterial establishment in naive broiler houses. J. Environ. Qual. 45 (3), 958–966. https://doi.org/10.2134/jeq2015.09.0492.

Burger, J., Gochfeld, M., 2005. Heavy metals in commercial fish in New Jersey. Environ. Res. 99, 403–412. https://doi.org/10.1016/j.envres.2005.02.001.

Caniça, M., Manageiro, V., Abriouel, H., Moran-Gilad, J., Franz, C.M.A.P., 2019. Antibiotic resistance in foodborne bacteria. Trends Food Sci. Technol. 84, 41–44.

Carrasco, E., Morales-rueda, A., García-gimeno, R.M., 2012. Cross-contamination and recontamination by Salmonella in foods : a review. Food Res. Int. 45 (2), 545–556. https://doi.org/10.1016/j.foodres.2011.11.004.

Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., Sánchez, A., 2018. Composting of food wastes: status and challenges. Bioresource Technology. https://doi.org/10.1016/j.biortech.2017.06.133.

Ceuppens, S., Titze, C., Quadros, R., De Bartz, S., César, E., Uyttendaele, M., 2014. Microbiological quality and safety assessment of lettuce production in Brazil. Int. J. Food Microbiol. 181, 67–76. https://doi.org/10.1016/j.ijfoodmicro.2014.04.025.

Chen, S., Lin, Y., Kao, Y., Shih, Y., 2013. Trace elements and heavy metals in poultry and livestock meat in Taiwan. Food Addit. Contam. B 6 (4), 231–236.

Cheruiyot, R., Parveen, S., Hashem, F., Bowers, J., 2016. Microbiological quality of fresh produce obtained from retail stores on the Eastern Shore of Maryland , United States of America. Food Microbiol. 56, 29–34. https://doi.org/10.1016/j.fm.2015.12.003.

Chu, Z., Fan, X., Wang, W., Huang, W., 2019. Quantitative evaluation of heavy metals ' pollution hazards and estimation of heavy metals ' environmental costs in leachate during food waste composting. Waste Manag. 84, 119–128. https://doi.org/10.1016/j.wasman.2018.11.031.

Clarke, R.M., Cummins, E., 2015. Evaluation of "Classic" and emerging contaminants resulting from the application of biosolids to agriculturallands: a review. Human and Ecological Risk Assessment 21 (2), 492–513. https://doi.org/10.1080/10807039.2014.930295.

Coelho, S.D., Sousa, A.C.A., Isobe, T., Kunisue, T., Nogueira, A.J.A., Shinsuke, T., 2016. Brominated flame retardants and organochlorine compounds in duplicate diet samples from a Portuguese academic community. Chemosphere 160, 89–94. https://doi.org/10.1016/j.chemosphere.2016.06.038.

Del Collo, L.P., Karns, J.S., Biswas, D., Lombard, J.E., Haley, B.J., Kristensen, R.C., Van Kessel, J.A.S., 2017. Prevalence, antimicrobial resistance, and molecular characterization of Campylobacter spp. in bulk tank milk and milk filters from US dairies. J. Dairy Sci. 100 (5), 3470–3479. https://doi.org/10.3168/jds.2016-12084.

Denis, N., Zhang, H., Leroux, A., Trudel, R., Bietlot, H., 2016. Prevalence and trends of bacterial contamination in fresh fruits and vegetables sold at retail in Canada. Food Contr. 67, 225–234. https://doi.org/10.1016/j.foodcont.2016.02.047.

DEP, M., 2019. State of Maine. Department of Environmental Protection.

Dickins, M.A., Franklin, S., Stefanova, R., Schutze, G.E., Eisenach, K.D., Wesley, I., Cave, M.D., 2002. Diversity of Campylobacter isolates from retail poultry carcasses and from humans as demonstrated by pulsed-field Gel electrophoresis. J. Food Protect. 65 (6), 957–962. https://doi.org/10.4315/0362-028x-65.6.957.

Dziubanek, G., Piekut, A., Rusin, M., Baranowska, R., Hajok, I., 2015. Contamination of food crops grown on soils with elevated heavy metals content. Ecotoxicol. Environ. Saf. 118, 183–189. https://doi.org/10.1016/j.ecoenv.2015.04.032.

Epstein, E., Chaney, R.L., Henrys, C., Locans, T.J., 1992. Trace elements in municipal solid waste compost. Biomass Bioenergy 3, 227–238.

Esposito, F., Nardone, A., Fasano, E., Scognamiglio, G., Esposito, D., Agrelli, D., Cirillo, T., 2018. A systematic risk characterization related to the dietary exposure of the population to potentially toxic elements through the ingestion of fruit and vegetables from a potentially contaminated area . A case study : the issue of the " Land of Fires " area. Environ. Pollut. 243, 1781–1790. https://doi.org/10.1016/j.envpol.2018.09.058.

Ezzariai, A., Hafidi, M., Khadra, A., Aemig, Q., El Fels, L., Barret, M., Pinelli, E., 2018. Human and veterinary antibiotics during composting of sludge or manure : global perspectives on persistence , degradation , and resistance genes. J. Hazard Mater. 359, 465–481. https://doi.org/10.1016/j.jhazmat.2018.07.092.

Fair, P.A., White, N.D., Wolf, B., Arnott, S.A., Kannan, K., Karthikraj, R., Vena, J.E., 2018. Persistent organic pollutants in fish from Charleston Harbor and tributaries, South Carolina, United States: a risk assessment. Environ. Res. 167, 598–613. https://doi.org/10.1016/j.envres.2018.08.001.

Fair, P.A., Wolf, B., White, N.D., Arnott, S.A., Kannan, K., Karthikraj, R., Vena, J.E., 2019. Perfluoroalkyl substances (PFASs) in edible fish species from Charleston Harbor and tributaries, South Carolina, United States: exposure and risk assessment. Environ. Res. 171, 266–277. https://doi.org/10.1016/j.envres.2019.01.021.

Farrell, M., Jones, D.L., 2009. Critical evaluation of municipal solid waste composting and potential compost markets. Bioresour. Technol. 100 (19), 4301–4310. https://doi.org/10.1016/j.biortech.2009.04.029.

Fegan, N., Jenson, I., 2018. The role of meat in foodborne disease : is there a coming revolution in risk assessment and management ? Meat Sci. 144, 22–29. https://doi.org/10.1016/j.meatsci.2018.04.018.

Ferrante, M.C., Fusco, G., Monnolo, A., Saggiomo, F., Guccione, J., Mercogliano, R., Clausi, M.T., 2017. Food contamination by PCBs and waste disposal crisis : evidence from goat milk in Campania (Italy). Chemosphere 186, 396–404. https://doi.org/10.1016/j.chemosphere.2017.07.144.

Filippinia, T., Tancredia, S., Malagolia, C., Cillonia, S., Malavoltia, M., Violia, F., Vincetia, M., 2019. Aluminum and tin Food contamination and dietary intake in an Italian Population. J. Trace Elem. Med. Biol. 52, 293–301.

Galani, J.H.Y., Houbraken, M., Wumbei, A., Djeugap, J.F., Fotio, D., Spanoghe, P., 2018. Evaluation of 99 pesticide residues in major agricultural products from the western highlands zone of Cameroon using QuEChERS method extraction and LC-MS/MS and GC-ECD analyses. Foods 7 (11), 184. https://doi.org/10.3390/foods7110184.

Garcia, C., Herñndez*, T., Costa, F., 1990. The influence of composting and maturation processes on the heavy-metal extractability from some organic wastes. Biol. Waste 31 (4), 291–301.

Garcia-Garcia, G., Woolley, E., Rahimifard, S., Colwill, J., White, R., Needham, L., 2017. A methodology for sustainable management of food waste. Waste and Biomass Valorization 8 (6), 2209–2227. https://doi.org/10.1007/s12649-016-9720-0.

Garcia-graells, C., Keersmaecker, S. C. J. De, Vanneste, K., Pochet, B., Vermeersch, K., Roosens, N., Botteldoorn, N., 2018. Detection of plasmid-mediated colistin resistance, mcr-1 and mcr-2 Genes, in Salmonella spp. isolated from food at retail in Belgium from 2012 to 2015. Foodbrone Pathogens and Disease 15 (2). https://doi.org/10.1089/fpd.2017.2329.

Geueke, B., Wagner, C.C., Muncke, J., 2014. Food contact substances and chemicals of concern : a comparison of inventories. Food Addit. Contam. 31 (8), 1438–1450. https://doi.org/10.1080/19440049.2014.931600.

Ghafur, A., Shankar, C., Gnanasoundari, P., Venkatesan, M., Mani, D., Thirunarayanan, M.A., Veeraraghavan, B., 2019. Detection of chromosomal and plasmid-mediated mechanisms of colistin resistance in Escherichia coli and Klebsiella pneumoniae from Indian food samples. Journal of Global Antimicrobial Resistance 16, 48–52. https://doi.org/10.1016/j.jgar.2018.09.005.

Ghisi, R., Vamerali, T., Manzetti, S., 2019. Accumulation of perfluorinated alkyl substances (PFAS) in agricultural plants : a review. Environ. Res. 169, 326–341. https://doi.org/10.1016/j.envres.2018.10.023.

Girihttps, S., Singh, A.K., 2019. Heavy metals in eggs and chicken and the associated human health risk assessment in the mining areas of Singhbhum copper belt , India. Arch. Environ. Occup. Health 74 (4), 161–170. https://doi.org/10.1080/19338244.2017.1407284.

Girotto, F., Alibardi, L., Cossu, R., 2015. Food waste generation and industrial uses : a review. Waste Manag. 45, 32–41. https://doi.org/10.1016/j.wasman.2015.06.008.

Glenn, L.M., Lindsey, R.L., Folster, J.P., Pecic, G., Boerlin, P., Gilmour, M.W., Frye, J.G., 2013. Antimicrobial resistance genes in multidrug-resistant Salmonella enterica isolated from animals, retail meats, and humans in the United States and Canada. Microb. Drug Resist. 19 (3), 175–184. https://doi.org/10.1089/mdr.2012.0177.

Griffin, M., Sobal, J., Lyson, T.A., 2009. An analysis of a community food waste stream. Agric. Hum. Val. 26 (1–2), 67–81. https://doi.org/10.1007/s10460-008-9178-1.

Gurtler, J.B., Doyle, M.P., Erickson, M.C., Jiang, X., Millner, P., 2018. Composting to inactivate foodborne pathogens for crop soil application : a review. J. Food Protect. 81 (11), 1821–1837. https://doi.org/10.4315/0362-028X.JFP-18-217.

Gustavsson, J., Cederberg, C., Sonesson, U., Otterdijk, R. van, Meybeck, A., 2011. Global food losses and food waste - extent, causes and prevention. SAVE FOOD: An Initiative on Food Loss and Waste Reduction. https://doi.org/10.1098/rstb.2010.0126.

Hadayat, N., De Oliveira, L.M., Da Silva, E., Han, L., Hussain, M., Liu, X., Ma, L.Q., 2018. Assessment of trace metals in five most-consumed vegetables in the US: conventional vs. organic. Environ. Pollut. 243, 292–300. https://doi.org/10.1016/j.envpol.2018.08.065.

Hajeb, P., Sloth, J.J., Shakibazadeh, S., Mahyudin, N.A., Afsah-Hejri, L., 2014. Toxic elements in Food : occurrence , binding , and reduction approaches. Compr. Rev. Food Sci. Food Saf. 13 (4), 457–472. https://doi.org/10.1111/1541-4337.12068.

HanaVojkovská, Panel, Myšková, P., Gelbíčová, T., Skočková, A., Koláčková, I., Karpíšková, R., 2017. Occurrence and characterization of food-borne pathogens isolated from fruit , vegetables and sprouts retailedskov a. Food Microbiol. 63 https://doi.org/10.1016/j.fm.2016.11.012.

Hargreaves, J.C., Adl, M.S., Warman, P.R., 2008. A review of the use of composted municipal solid waste in agriculture. Agric. Ecosyst. Environ. 123, 1–14. https://doi.org/10.1016/j.agee.2007.07.004.

Haukas, M., Berger, U., Hop, H., Gullikesen, B., Gabrielsen, G.W., 2007. Bioaccumulation of per- and polyfluorinated alkyl substances (PFAS) in selected species from the Barents Sea food web. Environ. Pollut. 148, 360–371. https://doi.org/10.1016/j.envpol.2006.09.021.

Heredia, N., Caballero, C., Carmen, C., Molina, K., Garcia, R., Solis, L., Leon, J., 2016. Microbial indicator profiling of fresh produce and environmental samples from farms and packing facilities in Northern Mexico. J. Food Protect. 79 (7), 1197–1209. https://doi.org/10.4315/0362-028X.JFP-15-499.

Hoagland, L., Ximenes, E., Ku, S., Ladisch, M., 2018. Foodborne pathogens in horticultural production systems: ecology and mitigation. Sci. Hortic. 236, 192–206.

Hogg, D., Lister, D., Barth, J., Favoino, E., Amlinger, F., 2009. OAV024 – Frameworks for Use of Compost in Agriculture in Europe. Eunomia Research & Consulting.

Hoha, G.V., Costăchescu, E., Leahu, A., Păsărin, B., 2014. Heavy metals contamination levels in processed meat marketed in Romania. Environmental Engineering and Management 13 (9), 2411–2415.

Holvoet, K., Sampers, I., Callens, B., Dewulf, J., 2013. Moderate prevalence of antimicrobial resistance in Escherichia coli isolates from lettuce, irrigation water and soil. Appl. Environ. Microbiol. 79 (21), 6677–6683. https://doi.org/10.1128/AEM.01995-13.

Hossain, M.B., Ahmed, A.S.S., Sarker, M.S.I., 2018. Human health risks of Hg, As, Mn, and Cr through consumption of fish , Ticto barb (Puntius ticto) from a tropical river , Bangladesh. Environ. Sci. Pollut. Control Ser. 25, 31727–31736.

Hu, Y., Zhang, W., Chen, G., Cheng, H., Tao, S., 2018. Public health risk of trace metals in fresh chicken meat products on the food markets of a major production region in southern China *. Environ. Pollut. 234, 667–676. https://doi.org/10.1016/j.envpol.2017.12.006.

Hudson, J.A., Frewer, L.J., Jones, G., Brereton, P.A., Whittingham, M.J., Stewart, G., 2017. The agri-food chain and antimicrobial resistance : a review. Trends Food Sci. Technol. 69, 131–147. https://doi.org/10.1016/j.tifs.2017.09.007.

Ikem, A., Egiebor, N.O., 2005. Assessment of trace elements in canned fishes (mackerel, tuna, salmon, sardines and herrings) marketed in Georgia and Alabama (United States of America). J. Food Compos. Anal. 18, 771–787. https://doi.org/10.1016/j.jfca.2004.11.002.

Ilic, S., Odomeru, J., LeJeune, J.T., 2008. Coliforms and prevalence of Escherichia coli and foodborne pathogens on minimally processed spinach in two packing plants. J. Food Protect. 71 (12), 2398–2403.

Iwamoto, M., Reynolds, J., Karp, B.E., Tate, H., Fedorka-Cray, P.J., Plumblee, J.R., Mahon, B.E., 2017. Ceftriaxone-resistant nontyphoidal Salmonella from humans, retail meats, and food animals in the United States, 1996-2013. Foodborne Pathogens and Disease 14 (2), 74–83. https://doi.org/10.1089/fpd.2016.2180.

Jiang, Y., Xie, S.H., Dennehy, C., Lawlor, P.G., Hu, Z.H., Wu, G.X., Gardiner, E., 2020. Inactivation of pathogens in anaerobic digestion systems for converting biowastes to bioenergy : a review. Renew. Sustain. Energy Rev. 120, 109654. https://doi.org/10.1016/j.rser.2019.109654.

Jogsten, I.E., Perelló, G., Llebaria, X., Bigas, E., Martí-Cid, R., Kärrman, A., Domingo, J. L., 2009. Exposure to perfluorinated compounds in Catalonia, Spain, through consumption of various raw and cooked foodstuffs, including packaged food. Food Chem. Toxicol. 47 (7), 1577–1583. https://doi.org/10.1016/j.fct.2009.04.004.

Johan, Bengtsson-Palme, 2017. Antibiotic resistance in the food supply chain: where can sequencing and metagenomics aid risk assessment? Current Opinion in Food Science 14, 66–71.

Johnston, L.M., Jaykus, L.-A., Moll, D., Martinez, M.C., Anciso, J., Mora, B., Moe, C.L., 2005. A field study of the microbiological quality of fresh produce. Retrieved from J. Food Protect. 68 (9), 1840–1847. http://www.ncbi.nlm.nih.gov/pubmed/16161682.

Johnston, L.M., Jaykus, L.A., Moll, D., Anciso, J., Mora, B., Moe, C.L., 2006. A field study of the microbiological quality of fresh produce of domestic and Mexican origin. Int. J. Food Microbiol. 112 (2), 83–95. https://doi.org/10.1016/j.ijfoodmicro.2006.05.002.

Jones, K.C., Voogt, P. De, 1999. Persistent organic pollutants (POPs): state of the science. Environ. Pollut. 100, 209–221.

Karumathil, D.P., Yin, H., Kollanoor-johny, A., Venkitanarayanan, K., 2016. Prevalence of multidrug-resistant bacteria on fresh vegetables collected from farmers' markets in Connecticut. J. Food Protect. 79 (8), 1446–1451. https://doi.org/10.4315/0362-028X.JFP-15-548.

Keskin, Y., Baskaya, R., Özyaral, O., Yurdun, T., Lüleci, N.E., Hayran, O., 2007. Cadmium, lead, mercury and copper in fish from the Marmara. Bull. Environ. Contam. Toxicol. 78, 258–261. https://doi.org/10.1007/s00128-007-9123-9.

Khan, M.U., Malik, R.N., Muhammad, S., Ullah, F., Qadir, A., 2015. Health risk assessment of consumption of heavy metals in market food crops from Sialkot and Gujranwala districts , Pakistan. Hum. Ecol. Risk Assess. 21, 327–337. https://doi.org/10.1080/10807039.2014.913445.

Koch, B.J., Hungate, B.A., Price, L.B., 2017. Food-animal production and the spread of antibiotic resistance : the role of ecology. Front. Ecol. Environ. 15 (6), 309–318. https://doi.org/10.1002/fee.1505.

Kohrman, H., Chamberlain, C.P., 2014. Heavy metals in produce from urban farms in the san francisco bay area. Food Addit. Contam. B 7 (2), 127–134. https://doi.org/10.1080/19393210.2013.859740.

Kupper, T., Bürge, D., Bachmann, H.J., Güsewell, S., Mayer, J., 2014. Heavy metals in source-separated compost and digestates. Waste Manag. 34, 867–874. https://doi.org/10.1016/j.wasman.2014.02.007.

Larrañaga, O., Brown-jaque, M., Quirós, P., Gómez-gómez, C., Blanch, A.R., Rodríguez-rubio, L., Muniesa, M., 2018. Phage particles harboring antibiotic resistance genes in fresh-cut vegetables and agricultural soil. Environ. Int. 115, 133–141. https://doi.org/10.1016/j.envint.2018.03.019.

Larsen, M.H., Dalmasso, M., Ingmer, H., Langsrud, S., Malakauskas, M., Mader, A., Jordan, K., 2014. Persistence of foodborne pathogens and their control in primary and secondary food production chains. Food Contr. 44, 92–109.

Lau, C.H., Engelen, K. Van, Gordon, S., Renaud, J., Topp, E., 2017. Novel antibiotic resistance determinants from agricultural soil exposed to antibiotics widely used in human medicine and animal farming. Appl. Environ. Microbiol. 83 (16).

Leong, D., Alvarez-ordóñez, A., Jordan, K., 2014. Monitoring occurrence and persistence of Listeria monocytogenes in foods and food processing environments in the Republic of Ireland. Front. Microbiol. 5, 436. https://doi.org/10.3389/fmicb.2014.00436.

Li, K., Weidhaas, J., Lemonakis, L., Khouryieh, H., Stone, M., Jones, L., Shen, C., 2017. Microbiological quality and safety of fresh produce in West Virginia and Kentucky farmers ' markets and validation of a post-harvest washing practice with antimicrobials to inactivate Salmonella and Listeria monocytogenes. Food Contr. 79, 101–108. https://doi.org/10.1016/j.foodcont.2017.03.031.

Li, H., Cheng, W., Li, B., Xu, Y., Zheng, X., 2020. The fate of antibiotic resistance genes during co-composting of swine manure with cauli fl ower and corn straw. Bioresour. Technol. 300, 122669. https://doi.org/10.1016/j.biortech.2019.122669.

Lian, M., Wang, J., Sun, L., Xu, Z., Tang, J., Yan, J., Zeng, X., 2019. Profiles and potential health risks of heavy metals in soil and crops from the watershed of Xi River in Northeast China. Ecotoxicol. Environ. Saf. 169, 442–448. https://doi.org/10.1016/j.ecoenv.2018.11.046.

Liang, H., Wu, W., Zhang, Y., Zhou, S., Long, C., Wen, J., Zou, F., 2018. Levels , temporal trend and health risk assessment of five heavy metals in fresh vegetables marketed in Guangdong Province of China during 2014-2017. Food Contr. 92, 107–120. https://doi.org/10.1016/j.foodcont.2018.04.051.

Liao, H., Friman, V.-P., Geisen, S., Zhao, Q., Cui, P., Lu, X., Zhou, S., 2019. Horizontal gene transfer and shifts in linked bacterial community Composition are associated with maintenance of antibiotic reistance genes during food waste composting. Sci. Total Environ. 660, 841–850.

Lin, L., Xu, F., Ge, X., Li, Y., 2018. Improving the sustainability of organic waste management practices in the food-energy-water nexus : a comparative review of anaerobic digestion and composting. Renew. Sustain. Energy Rev. 89, 151–167. https://doi.org/10.1016/j.rser.2018.03.025.

Liu, S., Kilonzo-nthenge, A., 2017. Prevalence of multidrug-resistant bacteria from U.S.-grown and imported fresh produce retailed in chain supermarkets and ethnic stores of Davidson County , Tennessee. J. Food Protect. 80 (3), 506–514. https://doi.org/10.4315/0362-028X.JFP-16-178.

Liu, Y.-Y., Wang, Y., Walsh, T.R., Yi, L.-X., Zhang, R., Spencer, J., Shen, J., 2016. Emergence of plasmid-mediated colistin resistance mechanism MCR-1 in animals and human beings in China: a microbiological and molecular biological study. Lancet Infect. Dis. 16 (2), 161–168. https://doi.org/10.1016/S1473-3099(15)00424-7.

Logan, T.J., Henry, C.L., Schnoor, J.L., Overcash, M., McAvoy, D.C., 1999. An assessment of health and environmental risks of trace elements and toxic organics in land-applied municipal solid waste compost. Compost Sci. Util. 7 (3), 38–53. https://doi.org/10.1080/1065657X.1999.10701973.

Luchansky, J.B., Chen, Y., Porto-Fett, A.C.S., Pouillot, R., Shoyer, B.A., Johnson-DeRycke, R., Dennis, S., 2017. Survey for Listeria monocytogenes in and on ready-to-eat foods from retail establishments in the United States (2010 through 2013): assessing potential changes of pathogen prevalence and levels in a decade. J. Food Protect. 80 (6), 903–921. https://doi.org/10.4315/0362-028x.jfp-16-420.

Ma, Y., Wilson, C.A., Novak, J.T., Riffat, R., Aynur, S., Murthy, S., Pruden, A., 2011. Effect of various sludge digestion conditions on sulfonamide, macrolide, and tetracycline resistance genes and class i integrons. Environ. Sci. Technol. 45 (18), 7855–7861. https://doi.org/10.1021/es200827t.

Mahmoud, A.F.A., Ikenaka, Y., Yohannes, Y.B., Darwish, W.S., Eldaly, E.A., Morshdy, A. E.M.A., Ishizuka, M., 2016. Distribution and health risk assessment of organochlorine pesticides (OCPs) residue in edible cattle tissues from northeastern part of Egypt: high accumulation level of OCPs in tongue. Chemosphere 144, 1365–1371. https://doi.org/10.1016/j.chemosphere.2015.10.016.

Makedonski, L., Peycheva, K., Stancheva, M., 2017. Determination of heavy metals in selected black sea fish species. Food Contr. 72, 313–318. https://doi.org/10.1016/j.foodcont.2015.08.024.

Margenat, A., Matamoros, V., Díez, S., Cañameras, N., Comas, J., Bayona, J.M., 2018. Occurrence and bioaccumulation of chemical contaminants in lettuce grown in peri-urban horticulture. Sci. Total Environ. 637–638, 1166–1174. https://doi.org/10.1016/j.scitotenv.2018.05.035.

Marine, S.C., Pagadala, S., Wang, F., Pahl, D.M., Melendez, M.V., Kline, W.L., Micalle, S. A., 2015. The growing season, but not the farming system , is a food safety risk determinant for leafy greens in the mid-Atlantic region of the United States. Appl. Environ. Microbiol. 81 (7), 2395–2407. https://doi.org/10.1128/AEM.00051-15.

Martinez, Jose Luis, 2009. Environmental pollution by antibiotics and by antibiotic resistance determinants. Environ. Pollut. 157 (11), 2893–2902.

Martinez, Jose L., Baquero, F., Anderson, D.I., 2007. Predicting antibiotic resistance. Nat. Rev. Microbiol. 5 (12), 958–965.

Mavrici, D., Yambao, J.C., Lee, B.G., Quiñones, B., He, X., 2017. Screening for the presence of mcr-1/mcr-2 genes in Shiga toxin-producing Escherichia coli recovered from a major produce-production region in California. PloS One 12 (11).

Mcauley, C.M., Mcmillan, K., Moore, S.C., Fegan, N., Fox, E.M., 2014. Prevalence and characterization of foodborne pathogens from Australian dairy farm environments. J. Dairy Sci. 97 (12), 7402–7412. https://doi.org/10.3168/jds.2014-8735.

McBride, M.B., Shayler, H.A., Spliethoff, H.M., Mitchell, R.G., Marquez-Bravo, L.G., Ferenz, G.S., Bachman, S., 2014. Concentrations of lead, cadmium and barium in urban garden-grown vegetables: the impact of soil variables. Environ. Pollut. 194, 254–261. https://doi.org/10.1016/j.envpol.2014.07.036.

Mehari, F., Greene, L.T., Duncan, L., Olawale Fakayode, S., 2015. Trace and macro elements concentrations in selected fresh fruits, vegetables, herbs, and processed foods in North Carolina, USA. J. Environ. Protect. 6 (6), 573–583. https://doi.org/10.4236/jep.2015.66052.

Meldrum, R.J., Ribeiro, C.D., Smith, R.M.M., Walker, A.M., Simmons, M., Worthington, D., Edwards, C., 2005. Microbiological quality of ready-to-eat foods : results from a long-Term surveillance program (1995 through 2003). J. Food Protect. 68 (8), 1654–1658.

Miller, Chaz, 2000. Profiles in Garbage: Food Waste | Waste360. Retrieved June 8, 2020, from https://www.waste360.com/mag/waste_profiles_garbage_food.

Miller, Cortney, Heringa, S., Kim, J., Jiang, X., 2013. Analyzing indicator microorganisms, antibiotic resistant Escherichia coli, and regrowth potential of foodborne pathogens in various organic fertilizers. Foodborne Pathogens and Disease 10 (6), 520–527. https://doi.org/10.1089/fpd.2012.1403.

Mol, S., Akay, K.U., Guney, G.Ç., 2018. Seafood safety at home : knowledge and practices. International Journal of Gastronomy and Food Science 13, 95–100. https://doi.org/10.1016/j.ijgfs.2018.07.003.

Monte, D.F., Mem, A., Fernandes, M.R., Cerdeira, L., Esposito, F., Galvão, J.A., Landgraf, M., 2017. Chicken meat as a reservoir of colistin-resistant Escherichia coli strains carrying mcr-1 genes in South America. Antimicrob. Agents Chemother. 61 (5) https://doi.org/10.1128/aac.02718-16 e02718-16.

Moon, H., Kim, D., Oh, J., 2019. Dietary exposure to PCBs by seafood cooking method : a Korean study. Chemosphere 215, 775–782. https://doi.org/10.1016/j.chemosphere.2018.10.044.

Mritunjay, S.K., Kumar, V., 2017. Microbial quality , safety , and pathogen detection by using quantitative PCR of raw salad vegetables sold in Dhanbad, India. J. Food Protect. 80 (1).

Muhterem-Uyar, M., Dalmasso, M., Bolocan, A.S., Hernandez, M., Kapetanakou, A.E., Kuchta, T., Wagner, M., 2015. Environmental sampling for Listeria monocytogenes control in food processing facilities reveals three contamination scenarios. Food Contr. 51, 94–107. https://doi.org/10.1016/j.foodcont.2014.10.042.

Mukherjee, A., Speh, D., Jones, A.T., Buesing, K.M., Diez-gonzalez, F., 2006. Longitudinal microbiological survey of fresh produce grown by farmers in the Upper Midwest. J. Food Protect. 69 (8), 1928–1936.

Nerín, C., Aznar, M., Carrizo, D., 2016. Food contamination during food process. Trends Food Sci. Technol. 48, 63–68.

NORS, C.D.C., 2019. National outbreak reporting system (NORS) dashboard | CDC. Retrieved June 26, 2020, from. https://wwwn.cdc.gov/norsdashboard/.

Olatunji, O.S., 2019. Evaluation of selected polychlorinated biphenyls (PCBs) congeners and dichlorodiphenyltrichloroethane (DDT) in fresh root and leafy vegetables using GC-MS. Sci. Rep. 1–10. https://doi.org/10.1038/s41598-018-36996-8. November 2018.

Oliver, J.P., Gooch, C.A., Lansing, S., Schueler, J., Hurst, J.J., Sassoubre, L., Aga, D.S., 2020. Invited review : fate of antibiotic residues , antibiotic-resistant bacteria , and antibiotic resistance genes in US dairy manure management systems. J. Dairy Sci. 103 (2), 1051–1071. https://doi.org/10.3168/jds.2019-16778.

Orzi, V., Scaglia, B., Lonati, S., Riva, C., Boccasile, G., Loris, G., Adani, F., 2015. The role of biological processes in reducing both odor impact and pathogen content during mesophilic anaerobic digestion. Sci. Total Environ. 526, 116–126. https://doi.org/10.1016/j.scitotenv.2015.04.038.

Pajurek, M., Pietron, W., Maszewski, S., Mikolajczyk, S., Piskorska-pliszczynska, J., 2019. Poultry eggs as a source of PCDD/Fs , PCBs , PBDEs and PBDD/Fs. Chemosphere 223, 651–658. https://doi.org/10.1016/j.chemosphere.2019.02.023.

Palisoc, S.T., Natividad, M.T., Jesus, N. De, Carlos, J., 2018. Highly sensitive AgNP/MWCNT/Nafion modified GCE-based sensor for the determination of heavy metals in organic and non-organic vegetables. Nature Scientific Reports (July), 1–13. https://doi.org/10.1038/s41598-018-35781-x.

Pedro, J., Castaño, A., Esteban, M., Bartolomé, M., Pérez-gómez, B., José, J., Es, B., 2018. Differential contribution of animal and vegetable food items on persistent organic pollutant serum concentrations in Spanish adults . Data from BIOAMBIENT . ES

project. Sci. Total Environ. 634, 235–242. https://doi.org/10.1016/j.scitotenv.2018.03.283.
Pepper, I.L., Brooks, J.P., Gerba, C.P., 2018. Antibiotic resistant bacteria in municipal wastes: is there reason for concern? Environ. Sci. Technol. 52 (7), 3949–3959. https://doi.org/10.1021/acs.est.7b04360.
Perelló, G., Martí-Cid, R., Llobet, J.M., Domingo, J.L., 2008. Effects of various cooking processes on theconcentrations of arsenic, cadmium, mercury, and lead in foods. J. Agric. Food Chem. 56, 11262–11269.
Perez-Arnedo, I., Gonzalez-Fandos, E., 2019. Prevalence of Campylobacter spp. in poultry in three Spanish farms, a slaughterhouse and a further processing plant. Foods 8 (3), 111. https://doi.org/10.3390/foods8030111.
Perez-Rodriguez, F., Taban, B.M., 2019. A state-of-art review on multi-drug resistant pathogens in foods of animal origin : risk factors and mitigation strategies. Front. Microbiol. 10, 2091. https://doi.org/10.3389/fmicb.2019.02091.
Pleissner, D., 2018. Recycling and reuse of food waste. Current Opinion in Green and Sustainable Chemistry 13, 39–43. https://doi.org/10.1016/j.cogsc.2018.03.014.
Rather, I.A., Koh, W.Y., Paek, W.K., Lim, J., 2017. The sources of chemical contaminants in food and their health implications. Front. Pharmacol. 8, 830. https://doi.org/10.3389/fphar.2017.00830.
Reddy, S.P., Wang, H., Adams, J.K., Feng, P.C.H., 2016. Prevalence and characteristics of Salmonella serotypes isolated from fresh produce marketed in the United States. J. Food Protect. 79 (1), 6–16. https://doi.org/10.4315/0362-028x.jfp-15-274.
Redmond, E.C., Griffith, C.J., 2003. Consumer food handling in the home : a review of food safety studies. J. Food Protect. 66 (1), 130–161.
Ripolles-avila, C., Hascoët, A.S., Martínez-suárez, J.V., Capita, R., Rodríguez-jerez, J.J., 2019. Evaluation of the microbiological contamination of food processing environments through implementing surface sensors in an iberian pork processing plant : an approach towards the control of Listeria monocytogenes. Food Contr. 99, 40–47. https://doi.org/10.1016/j.foodcont.2018.12.013.
Ronson, R.O.N.I.B., Ao, X.U.I.C., Abeka, R.O.W.D., 2007. Dietary exposure of Canadians to perfluorinated Carboxylates and perfluorooctane sulfonate via consumption of meat , fish , fast foods , and food items prepared in their packaging. J. Agric. Food Chem. 55, 3203–3210. https://doi.org/10.1021/jf0634045.
Schaider, L.A., Balan, S.A., Blum, A., Andrews, D.Q., Strynar, M.J., Dickinson, M.E., Peaslee, G.F., 2017. Fluorinated compounds in U.S. fast food packaging. Environ. Sci. Technol. 4 (3), 105–111. https://doi.org/10.1021/acs.estlett.6b00435.
Schecter, A., Colacino, J., Haffner, D., Patel, K., Opel, M., Päpke, O., Birnbaum, L., 2010a. Perfluorinated compounds, polychlorinated biphenyls, and organochlorine pesticide contamination in composite food samples from Dallas, Texas, USA. Environ. Health Perspect. 118 (6), 796–802. https://doi.org/10.1289/ehp.0901347.
Schecter, A., Haffner, D., Colacino, J., Patel, K., Päpke, O., Opel, M., Birnbaum, L., 2010b. Polybrominated diphenyl ethers (PBDEs) and hexabromocyclodecane (HBCD) in composite U.S. Food samples. Environ. Health Perspect. 118 (3), 357–362. https://doi.org/10.1289/ehp.0901345.
Scher, D.P., Kelly, J.E., Huset, C.A., Barry, K.M., Hoffbeck, R.W., Yingling, V.L., Messing, R.B., 2018. Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. Chemosphere 196, 548–555. https://doi.org/10.1016/j.chemosphere.2017.12.179.
Schwaiger, K., Helmke, K., Hölzel, C.S., Bauer, J., 2011. Antibiotic resistance in bacteria isolated from vegetables with regards to the marketing stage (farm vs . supermarket). Int. J. Food Microbiol. 148 (3), 191–196. https://doi.org/10.1016/j.ijfoodmicro.2011.06.001.
Scotti, R., Pane, C., Spaccini, R., Maria, A., Piccolo, A., Celano, G., Zaccardelli, M., 2016. On-farm compost : a useful tool to improve soil quality under intensive farming systems. Appl. Soil Ecol. 107, 13–23. https://doi.org/10.1016/j.apsoil.2016.05.004.
Seow, J., Ágoston, R., Phua, L., Yuk, H., 2012. Microbiological quality of fresh vegetables and fruits sold in Singapore. Food Contr. 25 (1), 39–44. https://doi.org/10.1016/j.foodcont.2011.10.017.
Sharma, J., Kumar, D., Hussain, S., Pathak, A., Shukla, M., V P K, Singh, S.P., 2019. Prevalence, antimicrobial resistance and virulence genes characterization of nontyphoidal Salmonella isolated from retail chicken meat shops in Northern India. Food Contr. 102, 104–111. https://doi.org/10.1016/j.foodcont.2019.01.021.
Shin, J., Rhee, C., Shin, J., Min, H., Gu, S., Mo, Y., 2020. Determining the composition of bacterial community and relative abundance of specific antibiotics resistance genes via thermophilic anaerobic digestion of sewage sludge. Bioresour. Technol. 311 (May), 123510. https://doi.org/10.1016/j.biortech.2020.123510.
Siebielska, I., Sidełko, R., 2015. Polychlorinated biphenyl concentration changes in sewage sludge and organic municipal waste mixtures during composting and anaerobic digestion. Chemosphere 126, 88–95. https://doi.org/10.1016/j.chemosphere.2014.12.051.
Sivagami, K., Vignesh, V.J., Srinivasan, R., Divyapriya, G., Nambi, I.M., 2018. Antibiotic usage, residues and resistance genes from food animals to human and environment : an Indian scenario. Journal of Environmental Chemical Engineering 102221. https://doi.org/10.1016/j.jece.2018.02.029.
Sjölund-Karlsson, M., Howie, R.L., Blickenstaff, K., Boerlin, P., Ball, T., Chalmers, G., Whichard, J.M., 2013. Occurrence of β-lactamase genes among non-typhi Salmonella enterica isolated from humans, food animals, and retail meats in the United States and Canada. Microb. Drug Resist. 19 (3), 191–197. https://doi.org/10.1089/mdr.2012.0178.
Smith, S.R., 2009. Organic contaminants in sewage sludge (biosolids) and their significance for agricultural recycling. Phil. Trans. Roy. Soc. Lond.: Mathematical, Physical and Engineering Sciences 367 (1904), 4005–4041.
Sonnier, J.L., Karns, J.S., Lombard, J.E., Kopral, C.A., Haley, B.J., Kim, S., Kessel, J., Van, A.S., 2018. Prevalence of Salmonella enterica, Listeria monocytogenes, and pathogenic Escherichia coli in bulk tank milk and milk filters from US dairy operations in the National Animal Health Monitoring System Dairy 2014 study. J. Dairy Sci. 101 (3), 1943–1956. https://doi.org/10.3168/jds.2017-13546.
Ssemanda, J.N., Reij, M.W., van Middendorp, G., Bouw, E., van der Plaats, R., Franz, E., Joosten, H., 2018. Foodborne pathogens and their risk exposure factors associated with farm vegetables in Rwanda. Food Contr. 89, 86–96. https://doi.org/10.1016/j.foodcont.2017.12.034.
Stasinakis, A.S., 2012. Review on the fate of emerging contaminants during sludge anaerobic digestion. Bioresour. Technol. 121, 432–440. https://doi.org/10.1016/j.biortech.2012.06.074.
Sun, J., Zeng, X., Li, X.P., Liao, X.P., Liu, Y.H., Lin, J., 2017. Plasmid-mediated colistin resistance in animals: current status and future directions. Anim. Health Res. Rev. 18 (2), 136–152. https://doi.org/10.1017/S1466252317000111.
Tang, Z., Xi, B., Huang, C., Tan, W., Li, W., Zhao, X., Xia, X., 2020. Mobile genetic elements in potential host microorganisms are the key hindrance for the removal of antibiotic resistance genes in industrial-scale composting with municipal solid waste. Bioresour. Technol. 301, 122723. https://doi.org/10.1016/j.biortech.2019.122723.
Traina, A., Bono, G., Bonsignore, M., Falco, F., Giuga, M., Maria, E., Sprovieri, M., 2019. Heavy metals concentrations in some commercially key species from Sicilian coasts (Mediterranean Sea): potential human health risk estimation. Ecotoxicol. Environ. Saf. 168, 466–478. https://doi.org/10.1016/j.ecoenv.2018.10.056.
Trimoulinard, A., Beral, M., Henry, I., Atiana, L., Porphyre, V., Tessier, C., Cardinale, E., 2017. Contamination by Salmonella spp., Campylobacter spp. and Listeria spp. of most popular chicken- and pork-sausages sold in Reunion Island. Int. J. Food Microbiol. 250, 68–74. https://doi.org/10.1016/j.ijfoodmicro.2017.03.017.
U.S. EPA, 2019. Advancing Sustainable Materials Management: Facts and Figures Report (November). Retrieved from. United States Environmental Protection Agency. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/advancing-sustainable-materials-management%0Ahttps://www.epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures-report.
U.S. EPA, 2020. Food Recovery Hierarchy | Sustainable Management of Food | US EPA. Retrieved May 31, 2020, from. https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy.
U.S. Food and Drug Administration, 2017. Pesticide residue monitoring program fiscal year 2017 pesticide report.
U.S. Food and Drug Administration, 2019. Analytical results of the total diet study | FDA. Retrieved April 15, 2020. https://www.fda.gov/food/total-diet-study/analytical-results-total-diet-study.
USEPA, 2009a. The national study of chemical residues in lake fish tissue.
USEPA, 2009b. The national survey of chemical residues in lake fish tissue.
Van, T.T.H., Yidana, Z., Smooker, P.M., Coloe, P.J., 2019. Antibiotic use in food animals in the world with focus on Africa: pluses and minuses. Journal of Global Antimicrobial Resistance 20, 170–177. https://doi.org/10.1016/j.jgar.2019.07.031.
Ventura, M., Cardoso, C., Bandarra, N.M., Delgado, I., Coelho, I., Gueifão, S., Castanheira, I., 2018. Bromine, arsenic, cadmium, and lead in several key food groups : an assessment of relative risk. Int. J. Environ. Anal. Chem. 98 (15), 1398–1412. https://doi.org/10.1080/03067319.2018.1559307.
Verraes, C., Boxstael, S. Van, Meervenne, E. Van, Coillie, E. Van, Butaye, P., Catry, B., Herman, L., 2013. Antimicrobial Resistance in the Food Chain : Rev. 10 (7l), 2643–2669. https://doi.org/10.3390/ijerph10072643.
Vikram, A., Miller, E., Arthur, T.M., Bosilevac, J.M., Wheeler, T.L., Schmidt, J.W., 2018. Similar levels of antimicrobial resistance in U.S. Food Service ground beef products with and without a "raised without antibiotics" claim. J. Food Protect. 81 (12), 2007–2018. https://doi.org/10.4315/0362-028x.jfp-18-299.
Wang, Y., Kannan, K., 2018. Concentrations and dietary Exposure to organophosphate esters in foodstuffs from Albany, New York, United States. J. Agric. Food Chem. 66, 13525–13532. https://doi.org/10.1021/acs.jafc.8b06114 research-article.
Weber, R., Herold, C., Hollert, H., Kamphues, J., Blepp, M., Ballschmiter, K., 2018. Reviewing the relevance of dioxin and PCB sources for food from animal origin and the need for their inventory , control and management. Environ. Sci. Eur. 30 (1), 42. https://doi.org/10.1186/s12302-018-0166-9.
Whitt, M., Brown, W., Danes, J.E., Vorst, K.L., 2016. Migration of heavy metals from recycled polyethylene terephthalate during storage and microwave heating. J. Plastic Film Sheeting 32 (2), 189–207. https://doi.org/10.1177/8756087915590190.
Witczak, A., Abdel-gawad, H., 2012. Comparison of organochlorine pesticides and polychlorinated biphenyls residues in vegetables , grain and soil from organic and conventional farming in Poland. Journal of Environmental Science and Health, Part B 47, 343–354. https://doi.org/10.1080/03601234.2012.646173.
Wu, Y., Zhang, H., Liu, G., Zhang, J., Wang, J., Yu, Y., Lu, S., 2016. Concentrations and health risk assessment of trace elements in animal-derived food in southern China. Chemosphere 144, 564–570. https://doi.org/10.1016/j.chemosphere.2015.09.005.
Xiong, L., Sun, Y., Shi, L., Yan, H., 2019. Characterization of antimicrobial resistance genes and class 1 integrase gene in raw meat and aquatic product , fresh vegetable and fruit , and swine manure in southern China. Food Contr. 104, 240–246. https://doi.org/10.1016/j.foodcont.2019.05.004.
Xu, Y., Noonan, G.O., Begley, T.H., 2013. Migration of perfluoroalkyl acids from food packaging to food simulants. Food Addit. Contam. 30 (5), 899–908. https://doi.org/10.1080/19440049.2013.789556.
Yang, S., Pei, X., Wang, G., Yan, L., Hu, J., Li, Y., Yang, D., 2016. Prevalence of food-borne pathogens in ready-to-eat meat products in seven different Chinese regions. Food Contr. 65, 92–98. https://doi.org/10.1016/j.foodcont.2016.01.009.
Zennegg, M., 2018. Dioxins and PCBs in meat – still a matter of concern ? CHIMIA International Journal for Chemistry 72 (10), 690–696. https://doi.org/10.2533/chimia.2018.690.
Zhang, J., Chen, M., Sui, Q., Wang, R., Tong, J., Wei, Y., 2016. Fate of antibiotic resistance genes and its drivers during anaerobic co-digestion of food waste and

sewage sludge based on microwave pretreatment. Bioresour. Technol. 217, 28–36. https://doi.org/10.1016/j.biortech.2016.02.140.

Zhao, C., Ge, B., Villena, J. De, Sudler, R., Yeh, E., Zhao, S., Meng, J., 2001. Prevalence of Campylobacter spp., Escherichia coli, and Salmonella serovars in retail chicken , Turkey , pork , and beef from the greater Washington , D.C., area. Appl. Environ. Microbiol. 67 (12), 5431–5436. https://doi.org/10.1128/AEM.67.12.5431.

Zhao, S., Young, S.R., Tong, E., Abbott, J.W., Womack, N., Friedman, S.L., McDermott, P. F., 2010. Antimicrobial resistance of campylobacter isolates from retail meat in the United States between 2002 and 2007. Appl. Environ. Microbiol. 76 (24), 7949–7956. https://doi.org/10.1128/AEM.01297-10.

Zhou, X., Zheng, N., Su, C., Wang, J., 2019. Relationships between Pb, As, Cr, and Cd in individual cows ' milk and milk composition and heavy metal contents in water , silage , and soil *. Environ. Pollut. 255, 113322. https://doi.org/10.1016/j.envpol.2019.113322.

Zuliani, T., Vidmar, J., Drinčić, A., Ščančar, J., Horvat, M., Nečemer, M., Milačič, R., 2019. Potentially toxic elements in muscle tissue of different fi sh species from the Sava River and risk assessment for consumers. Sci. Total Environ. 650, 958–969. https://doi.org/10.1016/j.scitotenv.2018.09.083.

Zwe, Y.H., Tang, V.C.Y., Aung, K.T., Gutiérrez, R.A., Ng, L.C., Yuk, H.-G., 2018. Prevalence, sequence types, antibiotic resistance and, gyrA mutations of Salmonella isolated from retail fresh chicken meat in Singapore. Food Contr. 90, 233–240. https://doi.org/10.1016/j.foodcont.2018.03.004.

Bodiguel, X., Tronczynski, J., Loizeau, V., Munschy, C., Guiot, N., Guellec, A. M., Le, Mellon, C. (2008). Classical and novel organohalogen compounds (PCBs and PBDEs) in hake (M . merluccius , L .) from the Mediterranean and Atlantic coasts (France). Environmental Toxicology II, 110, 157–166. https://doi.org/10.2495/ETOX080171.