



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.

Protein-Rich By-Products: Production Statistics, Legislative Restrictions, and Management Options

T.M. Hicks, C.J.R. Verbeek

School of Engineering, Faculty of Science and Engineering, University of Waikato,
Hamilton, New Zealand

1 INTRODUCTION

Most of the world's food is derived from agricultural, horticultural, and fishery processes. With a growing population, urbanization, and increased income, the food industry has become increasingly market driven. As a result of globalization and reduced trade barriers, it has grown to account for approximately 10% of the world's gross domestic product (Murray 2007). Fortunately, environmental protection and sustainability are currently better aligned with the world's consumption of natural resources. Over the past few decades, it has tried to adopt technologies to improve waste minimization and environmental performance. Although the most valuable elements are extracted from foods during harvest and processing, what remains in both the product-specific and product-nonspecific

wastes may also contain other potentially valuable components.

Predicting future food production and associated by-products is complicated and has to take into account not only changes in population size, dietary composition, land requirements, and primary resources, but also climate and environmental aspects (Godfray et al., 2010a). Overall, increased global demand for animal-based products requires a substantially greater increase in plant and other feed resources, which will subsequently generate a much larger volume of protein-rich materials than currently produced.

The quantity of food materials wasted each year is exorbitant, and urbanization and the increasing per capita income will see this quantity rise further through increased consumption of staple foods and through diversification into animal products, such as meat, fish, and dairy. This

will be most challenging for transitional countries, which are expected to undergo a much more rapid increase in per capita meat consumption compared to high-income countries (ie, China will increase by ~50%, from 49 kg in 2000 to 74 kg per capita per year in 2030 compared to an increase of ~9%, from 86 kg to 95 kg per capita per year, in higher income countries) (Msangi and Rosegrant, 2011). Such nutritional transitions result in a rapid increase in animal products, putting a significant amount of pressure on food supply chains within transitional countries than those in the developed world.

A major facet of the problem we face, is being able to source adequate quantities of high-quality protein from which to feed both humans and animals, without intensifying the overall environmental impact (van Huis, 2013). Obviously, increasing production of animal-based products will result in a much higher consumption of grain and protein feeds to feed livestock, which are estimated to require ~6 kg of plant protein for every kilogram of protein they produce (Pimentel and Pimentel, 2003). However, this could be better perceived by the ~30 kg of grain required to produce 1 kg of edible boneless meat from grain-fed cattle (Foley, 2011). Conversely, while chicken and pork are more efficient converters of plant proteins, pasture-fed cattle are able to convert nonfood material into usable protein.

The technology for recovering nutrients and usable materials from industry is often feasible, but the regulations regarding what can be done with by-products of industry may not always allow for the technology to be adopted. Despite a concerted effort to better use by-products of the agricultural and food industry to improve the management of resources, sensible legislative incentives also need to be implemented. This chapter identifies areas of food production and related industries generating waste and by-products with high levels of recoverable protein, in particular, those derived from agricultural production itself. Current and future management options for the transformation and/or

disposal of these wastes and by-products are then considered in light of current legislation and technological restrictions.

2 FOOD PRODUCTION CYCLE AND BY-PRODUCTS

The modern food cycle is comprised of several stages, including agricultural production, postharvest handling and storage, food processing and packaging, distribution and retail, and finally, end-of-life and consumption (Fig. 1.1) (Kummu et al., 2012). Agricultural production, postharvest handling, and storage of food give rise to unintended food losses and ancillary by-products, while processing and packaging and distribution and retail result in “food waste.” Food loss, by-products, and food waste are formed at every stage of the food production process. While the generation of by-products, such as crop residues and animal by-products (ABPs) during agricultural production is considered unavoidable, food losses, owing to a lack of market or degradation during handling or transportation could be avoided with care, but when considering statistics, it is often difficult to distinguish between the two.

For various reasons, approximately one-third of the food produced worldwide is wasted (Godfray

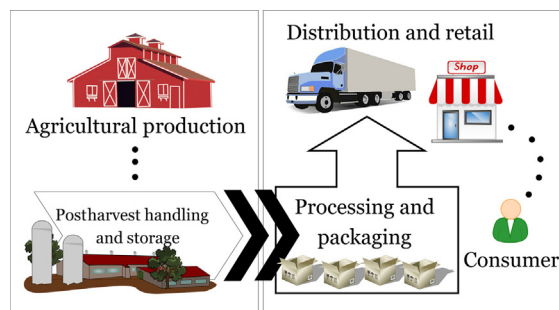


FIGURE 1.1 General food production stages, starting from agricultural production and postharvest handling and storage to processing and packaging, distribution, retail, and consumption.

et al., 2010a; Food and Agriculture Organization of the United Nations, 2011). These wastes (and possible by-products) are created during the manufacturing processes and are often removed in order to give the product the desired sensory and nutritional qualities. Although the magnitude of food losses, by-products, and food waste varies depending on the product type (Table 1.1) and the stage of production considered (Table 1.2), it is strongly influenced by the technology and infrastructure available to the region.

It has been estimated that around 60 million metric tons (MMT) of ABPs are produced worldwide every year (Leoci, 2014), along with significantly higher quantities of crop residues (Santana-Méridas et al., 2012). Obviously, industrial processing of any food, whether it is intended for human or animal consumption (or other industrial processes, such as biofuels) leads to a vast quantity of waste and by-products, typically ranging between 30 and 60% by weight (Table 1.1). In the case of crops, only 60% of global production is used for human consumption, mostly in the form of grains, pulses, oil plants, fruits, and vegetables, leaving 35% as by-products (used for animal fodder) and the remaining 5% for conversion to biofuel and other industrial products (Foley, 2011).

In high-income regions, most food waste occurs during distribution and consumption, with high losses also occurring during agricultural production of plant products and fish (Table 1.2). Harvesting of crops also results in an inedible portion of the biomass (including edible product lost during harvest) contributing to what is known as *crop residues*. For most common edible crops, the residue-to-crop-production ratio is between 0.9 and 3 to 1 (Scarlat et al., 2010). This mass is not accounted for in Table 1.2, however, typical quantities of some common food crops are given in Table 1.3. In lower-income regions, losses occur at every stage, particularly post-harvest, to a much higher degree, but occur significantly less at the consumption stage. Higher losses throughout production in low-income regions are an artefact of inadequate knowledge,

TABLE 1.1 Percentage of By-Products and Waste Generated During Different Production Processes

Production process	Converted to waste and by-products (%)
PLANT PRODUCTS	
Cornstarch production	41–43
Fruit and vegetable processing	5–30
Potato starch production	80
Red wine production	20–30
Sugar production from sugar beet	86
Vegetable oil production	40–70
Wheat starch production	50
ANIMAL PRODUCTS	
Beef slaughter	40–52
Crustacean processing	50–60
Fish canning	30–65
Fish filleting, curing, salting, smoking	50–75
Cheese production	85–90
Mollusk processing	20–50
Pig slaughter	35
Poultry slaughter	31–38
Yogurt production	2–6

Adapted from de las Fuentes et al. (2004).

skills, technologies, and infrastructure to support the food supply chain compared to the industrialized world (Godfray et al., 2010b).

Globally, billions of tons of agro-industrial residues and by-products are generated annually (Table 1.3). These include solid, liquid, and gaseous residues and can be seen as one of the most abundant, cheap, and renewable resources available (Santana-Méridas et al., 2012). Given that food waste has a typical composition of ~30–60 wt.% starch, 10–40 wt.% lipids, and 5–10 wt.% protein (Pleissner and Lin, 2013), millions of tons of protein, from plant and animal sources, could be better used. Agricultural production also has other unavoidable wastes

TABLE 1.2 Combined Food Losses and Food Waste for Each Stage of the Food Production Chain, Expressed as a Weight Percentage of the (Edible Only) Incoming Resource

	Agricultural production (wt.%)	Postharvest handling and storage (wt.%)	Processing and packaging (wt.%)	Distribution (wt.%)	Consumption (wt.%)
<i>HIGH INCOME</i>					
Cereals	2	2–10	0.5–10	2	20–27
Roots and tubers	20	7–10	15	7–9	10–30
Oilseeds and pulses	6–12	0–3	5	5	4
Fruits and vegetables	10–20	4–8	2	8–12	15–28
Meat	2.9–3.5	0.6–1	5	4–6	8–11
Fish and seafood	9.4–15	0.5–2	6	9–11	8–33
Milk and dairy	3.5	0.5–1	1.2	0.5	5–15
<i>LOW INCOME</i>					
Cereals	6	4–8	2–7	2–4	1–12
Roots and tubers	6–14	10–19	10–15	3–11	2–6
Oilseeds and pulses	6–15	3–12	8	2	1–2
Fruits and vegetables	10–20	9–10	20–25	10–17	5–12
Meat	5.1–15	0.2–1.1	5	5–7	2–8
Fish and seafood	5.1–8.2	5–6	9	10–15	2–4
Milk and dairy	3.5–6	6–11	0.1–2	8–10	0.1–4

Regions were grouped (Gustavsson et al. 2011) into medium- to high-income regions (Europe, United States, Canada, Oceania, and industrialized Asia) and low-income regions (sub-Saharan Africa, North Africa, West and Central Asia, South and Southeast Asia, and Latin America).

associated with it, including manure and effluent, which also contain high levels of recoverable protein. These by-products and wastes find new life, often as animal feed ingredients.

3 PROTEIN-RICH BY-PRODUCTS

Waste materials generated during agricultural production, including inedible plant and animal parts, are removed during harvesting and postharvest processing. Other unavoidable nutrient-rich wastes, such as manure and deadstock, are also produced. Due to their high levels of recoverable protein, carbohydrate and fiber, many of the by-products and wastes of the agricultural industry currently find reuse as animal feeds or animal feed ingredients.

Animal feed ingredients are blended in such a way as to create a more nutritious food for livestock. Plant-derived ingredients include grains, such as maize, barley, sorghum, oats, and wheat (which can also be used for bioethanol production), from which the by-products are often diverted back to feed. These grain by-products include corn gluten meal, brewers and distiller's grains, malt sprouts, brewer's yeast, and wheat mill feed (Lefferts et al., 2006; Naik et al., 2010). More importantly, it has been assumed that by 2020, up to 10% of transportation fuels will be derived from biofuels, generating up to 100 MMT of additional protein (Scott et al., 2007). Higher value applications for inedible and nonessential amino acids derived from these by-products may eventually be commercialized, providing a feedstock for protein-based plastics,

TABLE 1.3 Estimates of Production By-Products and Crop Residues from Commodity Crops in Million Metric Tons (MMTs) Per Annum ([Santana-Méridas et al. 2012](#))

Production process	Residue production (MMT/year)	Production process	Residue production (MMT/year)
<i>Roots and tubers</i>		<i>Cereals</i>	
Potato foliage, tops peels and pulps	116.7	Rice straw	457.0
Cassava peels, stalks, bagasse	82.6	Wheat straw	475.1
<i>Fruits</i>		Barley straw	105.0
Apple pomace	20.9	Maize straw and stalks	1266.6
Orange peels, pulps and membranes	34.7	Maize cobs	337.8
<i>Legumes</i>		Millet	88.9
Beans straw and pods	57.2	Banana leaves, stems/peels	183.8
Soybeans straw and pods	392.7	Grape pomace	20.5
<i>Oil crops</i>		<i>Slaughterhouse By-products</i>	
Sunflower foliage/stems	15.3	Cattle	
Olive leaves and stems	10.3	Protein meal	6.9
Coconut shells, husks/fronts	18.7	Tallow	4.2
Palm oil shells, husks/fronts	13.5	Bloodmeal	0.38
Groundnuts stalks/shells	71.1	Sheep	
Rapeseed straw	73.8	Protein meal	0.58
Cottonseed stalks	80.1	Tallow	0.59
<i>Tree nuts</i>		Bloodmeal	0.05
Almond hulls and shells	0.9	Pigs	
Walnut shells	1.70	Protein meal	3.7
<i>Industrial crops</i>		Tallow	7.6
Sugarcane leaves and tops	168.5	Bloodmeal	0.34
Cotton stalks	197.6	Chicken	
Fiber crops leaves/stalks	56.9	Protein meal	5.5
<i>Vegetables</i>		Tallow	2.6
Onion leaves and stems	35.0	Bloodmeal	0.18
Tomatoes leaves and stems	72.9	Fish	
Cucumber leaves and stems	25.9	Protein meal	6.2

Slaughterhouse by-products calculated from the proportion of live weight in each rendering product for each species considered ([Wiedemann and Yan, 2014](#)), using the 2013 estimate of livestock slaughtered globally ([Food and Agriculture Organization of the United Nations, 2013](#)). Fishmeal estimate from 2002 ([Hardy and Tacon, 2002](#)).

biopesticides or commodity organic compounds (Naik et al., 2010; Scott et al., 2007).

Oil production by-products (oil meals and press cakes) from processing oilseeds, such as soybean, canola, sunflower seed, linseed, palm kernel and others, are also important feed ingredients. Oil meals are obtained by solvent extraction of the oil cakes, which are obtained by pressing the seed. In 2013, 269 MMT of various oil meals were produced globally, of which 181 MMT was soymeal (United States Department of Agriculture, 2015a). In the United States alone, 36 MMT of soymeal is produced annually (United States Department of Agriculture, 2015a), representing more than two-thirds of the proteinaceous animal feed in the country (Lefferts et al., 2006). Other oilseed meals are lower in protein and higher in fiber and are often used for feeding ruminants. Cottonseed meal is also high in protein and is mainly used as cattle feed in the United States or as aquaculture feed. Unlike other seeds, the press cake obtained from castor seeds during castor oil production is inedible because of its high level of phytotoxins (ricin, a toxic protein), hydrocyanides, and other allergens, however, this too has a high level of protein, ~20–30% (Table 1.4).

Other plant ingredients may include alfalfa by-products, such as alfalfa meal, pellets, and concentrated alfalfa solubles, which are typically fed to ruminants. Further, various nuts, seeds, and their by-products, such as hulls and seed screenings; legume by-products, such as bean straw meal and hulls; and even dried roots and tubers, such as sweet potatoes and chipped or pelletized cassava, find use in animal feed.

Agricultural production—specifically the production of animal-derived goods—also results in by-products. In fact, around 30 wt.% of an animal produced for food is not used directly for human consumption, and downed or dead animals are another waste artefact of production. These waste materials are processed by the rendering industry, producing protein-rich products (Table 1.4). Global production of ABP

meals from rendering is in excess of 13 MMT per year (Fig. 1.2). These products include meat meal, meat and bone meal, poultry by-product meal, poultry meal, blood meal, feather meal, hydrolyzed leather and leather meal, eggshell meal, hydrolyzed hair, unborn calf carcasses, ensiled paunch, bone marrow, and dried plasma (Lefferts et al., 2006).

Other than the preceding, about 30 wt.% of the fish caught globally each year is not used directly for human consumption; instead it is used to produce protein-rich marine by-products, in excess of 6 MMT per annum (Table 1.4). Typical animal feed ingredients derived from marine origin include fishmeal, dried fish solubles, crab meal, shrimp meal, fish protein concentrate, and other fish by-products (Lefferts et al., 2006).

Finally, animal waste has also been used as a feed ingredient, including dried ruminant waste (manure), dried poultry waste, dried poultry litter, dried swine waste, undried processed animal waste products, and processed animal waste derivatives (Lefferts et al., 2006). According to the Association of American Feed Control Officials, in the United States, these processed animal waste products must be treated appropriately to ensure that the product is free of harmful pathogens, pesticide residues, parasites, heavy metals, or drug residues (Association of American Feed Control Officials, 2007). Although recycled animal wastes have been knowingly incorporated into animal feed for almost 50 years, the Food and Drug Administration does not endorse the use of recycled animal waste (Lefferts et al., 2006). Regardless, protein content in dried manure ranges from 12 to 18 wt.% for cattle, 28 to 48 wt.% for poultry, and 22 to 25 wt.% for pigs (Chen et al., 2003), making it another source of valuable protein and nutrients.

Just as the sources of waste are diverse, so too are the wastes generated, each with a different chemical and physical makeup, directly affecting how they are best used (Table 1.5). Many studies focused on the valorization of these and

TABLE 1.4 Typical Protein Content and US and Global Production Quantities in Million Metric Tons (MMTs) of Some Protein Meals Produced from the Agricultural Industry

Protein meal	Crude protein (%)	References	US production (MMTs)	Global production (MMTs)
<i>PLANT PRODUCTS</i>				
Alfalfa meal	19.2	National Research Council (2001)	0.513–1.91 ^a	
Canola seed meal	37.8	National Research Council (2001)	1.07 ^b	
Castor seed cake	31–36	Annongu and Joseph (2008); Fuller et al. (1971)		
Castor seed meal	20.8	Annongu and Joseph (2008)		
Corn gluten meal	53.9–65.0	National Research Council (2001); Adeola (2003); Agunbiade et al. (2004)	5.9 ^a	
Cottonseed cake	21.1–57.3	Kassahun et al. (2012); Pousga et al. (2007); Khanum et al. (2007)		
Cottonseed meal	34.3–44.9	National Research Council (2001); Khanum et al. (2007); El-Saidy and Gaber (2003)	0.82–1.09 ^{ab}	10.3–15.5 ^{ac}
Cow pea seed meal	32.7	El-Saidy and Saad (2008)		
Linseed cake	34.7	Kassahun et al. (2012)		
Linseed meal	32.6–35.4	National Research Council (2001); El-Saidy and Gaber (2003)	0.142–0.147 ^{ab}	1.02 ^a
Peanut meal	51.8	National Research Council (2001)	0.12–0.159 ^{ac}	4.32–6.83 ^{ab,c}
Rapeseed cake	35.6	Kassahun et al. (2012)		
Rapeseed meal	34.1–37.9	Khanum et al. (2007); Chu et al. (2014)		39.2 ^b
Sesame seed cake	32.8	Kassahun et al. (2012)		
Soybean cake	40.1–49.1	Agunbiade et al. (2004); Kassahun et al. (2012)		
Soybean meal	44.4–53.8	National Research Council (2001); El-Saidy and Gaber (2003); Chu et al. (2014)	39.1 ^b	200.8 ^b
Sunflower meal	28.4–42.0	National Research Council (2001); El-Saidy and Gaber (2003)	0.23–0.29 ^{ab}	16.0 ^b
<i>ANIMAL PRODUCTS</i>				
Bloodmeal	80.2–100.5	Martínez-Llorens et al. (2008); Haughey (1976); National Research Council and Canadian Department of Agriculture (1971); Preston (2014)		
Feather meal			0.63 ^d	
Hydrolyzed feather meal	81.2–92	National Research Council (2001); Preston (2014); Nengas et al. (1995)		
Meat and bone meal	49.5–59.4	National Research Council (2001); National Research Council and Canadian Department of Agriculture (1971); Preston (2014); Nengas et al. (1995); Garcia and Phillips (2009); Howie et al. (1996); Kamalak et al. (2005)	1.8–2.1 ^{d,e}	
Meat meal	51.7–58.4	National Research Council (2001); Kamalak et al. (2005); Qiao and Thacker (2004)	2.4 ^a	

(Continued)

TABLE 1.4 Typical Protein Content and US and Global Production Quantities in Million Metric Tons (MMTs) of Some Protein Meals Produced from the Agricultural Industry (*cont.*)

Protein meal	Crude protein (%)	References	US production (MMTs)	Global production (MMTs)
Fish meal	59.0–68.5	National Research Council (2001); Qiao and Thacker (2004); Bimbo (2000); Trushenski and Gause (2013)	0.33 ^a	4.1–6.2 ^{a,b,f}
Poultry by-product meal	51.7–63	Preston (2014); Nengas et al. (1995); Kamalak et al. (2005); Trushenski and Gause (2013)	1.2 ^d	
Shrimp meal	22.8–50	Preston (2014); Okoye et al. (2005); Fanimo et al. (2000); Everts et al. (2003); Fanimo et al. (2006)		

^a Based on production statistics for 1989–1990 in *Animal Feeds Compendium* (1992) (Ash, 1992).

^b Based on a forecast for production quantities for 2014 in *USDA Agricultural Statistics* (2015) (United States Department of Agriculture, 2015b).

^c Based on production statistics for 2003–2012 in *USDA Agricultural Statistics* (2013) (United States Department of Agriculture, 2013).

^d Based on 2012 US Rendering Market Report (2013) (Swisher, 2013).

^e Based on US manufacturing statistics from 1992 (United States Department of Commerce, 1994).

^f Fishmeal production statistics 2002 (Hardy and Tacon, 2002).

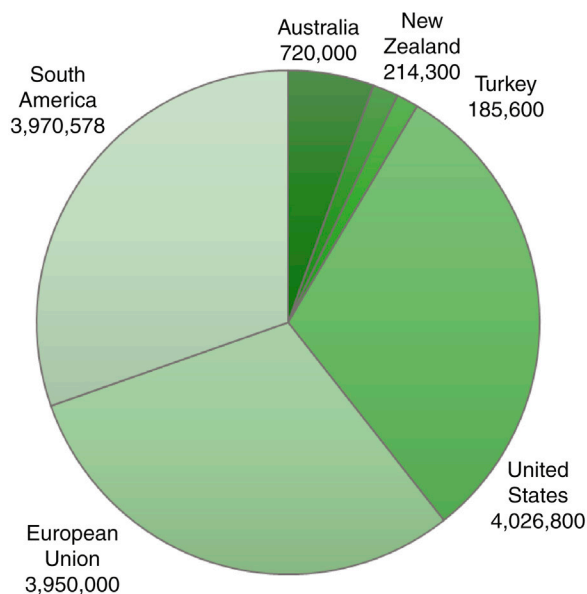


FIGURE 1.2 Global production estimates for animal by-product protein meals expressed in metric tons (Kaluzny 2013). Total global production ~13 million metric tons.




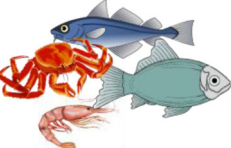
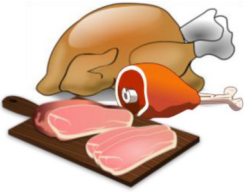
other waste streams in a profitable way. Obviously, for protein meals that can be fed to livestock or fish, the price for which they are sold will generally cover the cost of producing them, and in the case of ABPs, the revenue generates a

reasonable profit. However, for inedible protein meals (including meals which either have no market or limited market access), adding value through conversion into novel products is of greater necessity. The problems with imparting additional value to these products is not necessarily related to the scientific or technological feasibility or even cost, but are most commonly associated with the perceived risks and often restrictive supporting legislation.

4 BIOSECURITY AND RISK GOVERNANCE


Every nation strives to maintain its biosecurity to protect its ecological and economic resources from disease and invasive pests. The most effective means of governing the risks posed by the importation of dangerous or questionable materials, and the harm they may cause to animals or humans, is to impose legal restrictions. The importance of maintaining biosecurity is most apparent when considering the risks of international trading. The introduction of invasive pests and disease through international trade could lead to adverse effects, not only on plant

TABLE 1.5 Residues of Food Processing and By-Products

Industry	Food processed	Residues and by-products	Products from by-products
PLANTS			
 Grain crops	Grain, flour, bread, biscuits, crackers, cakes starch, bakery goods	Straw, stems, leaves, husks, cobs, hulls, fiber, bran, germ, gluten, steep liquor	Biomass for ethanol production
 Fruits and vegetables	Tinned fruits and vegetables, juices, vegetable oils, starches, sugars	Rotten fruits and vegetables, stem waste, pits, seeds, peels, pulp	Pectin, pigments, sweeteners, antioxidants, essential oils, proteins, vitamins, sterols, ethanol, yeast, enzymes
 Edible oils	Oils, hydrogenated fats	Press solids and oil cakes, oil water emulsions, rancid fats, shells of oilseeds	Biosurfactants
ANIMALS			
 Fish and seafood	Canned fish, filleted fish, smoked fish, salted fish, processed crustaceans and mollusks	Scales, fins, bones, guts, fish oil and shells	Fishmeal, fish oil, polyunsaturated fatty acids, fish protein concentrate, hydrolysate, collagen, gelatine, chitin, chitosan, calcium carbonate
 Meat	Processed meat and poultry products	Blood, hides, hair, heads, horns, hooves, offal, fat, meat trimmings, feathers, feet, giblets	Bloodmeal, meat meal, fat, feather meal, hydrolysate, bone meal, plasma, red blood cells, collagen, gelatine

(Continued)

TABLE 1.5 Residues of Food Processing and By-Products (*cont.*)

Industry	Food processed	Residues and by-products	Products from by-products
 Dairy	Milk, butter, cream, yogurt, cheese, ice cream	Whey, wastewater	Whey protein

Adapted from de las Fuentes et al. (2004) and Ramachandran et al. (2007).

and animal health, but biodiversity and food production as a whole, and should be appropriately managed (Maye et al., 2012).

These measures must consider not only the scientific evidence supporting such a restriction, but must also consider any reasonable precautions that can act to offset any deficiencies in a solely scientific approach. Hence, during the development of a new policy, a risk analysis is first performed, followed by evaluation of that risk through the lens of current legal, institutional, social, and economic circumstances, all of which is undertaken by the stakeholders who represent them (Mills et al., 2011). As such, risk governance deals with the management of both perceived and scientifically founded risks.

Although risk management implemented through public policy is focused at the national level, many food and natural resource policies operate at levels both below and beyond the national level (Mills et al., 2011). However, as a result of the discrepancies between each state's local policy making and a lack of cohesive global regulations, the intersection between risk and commerce continues to be a major challenge facing the international trading system.

A significant amount of trade conflict experienced at the World Trade Organization has involved the United States, Canada, and/or the European Union (Hornsby, 2013). Some topics

that became the focus of either formal or informal disputes have included hormone-fed beef, bovine spongiform encephalopathy (BSE), raw milk cheese, genetically modified organisms, chlorine-washed chicken, and wood packing materials. Such disputes imply the presence of a transatlantic divide over what constitutes a legitimate risk regulation, however, this is an oversimplification. Although the risk regulations set forth by the European Union take a precautionary approach, acting in light of scientific uncertainty and taking into account public concerns, the US system is based on a "sound science" approach, free from political influence, however, this has not always been the case. It has been argued that the United States used to be more precautionary than the European Union (Hornsby, 2013), but was pressured to limit the calculation of risk in public policy. The EU's regulatory failures during food safety crises served to undermine public trust in the EU institutions, resulting in the use of a precautionary approach (Hornsby, 2013). Overall, it has also been proposed that both regions partake in "occasional and selective application of precaution to different risks in different places and time" (Wiener, 2011). Nevertheless, there are some consistencies around the world regarding the safe handling, distribution, and disposal of food, animal wastes, and by-products.

5 POLICY REGARDING PLANT AND ANIMAL BY-PRODUCTS

The degree to which protein by-products, particularly ABPs, can be used is limited by the customs, religions, and regulatory requirements of the region. All feedstuffs imported into a country must comply with rules regarding hygiene, traceability, contaminants, labeling requirements, and health issues given its expected use. The use of the product is then subject to more specific rules, largely limiting the use of those feedstuffs containing animal-derived products. The first diagnosis of BSE in the United Kingdom in 1986 and the subsequent publication in 1996 that new variant Creutzfeldt–Jakob disease in humans had most probably arisen from exposure to BSE-infected meat, sparked a global crisis with respect to food safety and risk management.

Up until the outbreak of BSE during the 1980s, almost all protein by-products were used as feed supplements for livestock. In 1989, the practice of feeding ruminant animal protein meals to other ruminants was banned, along with the use of specified bovine offal (brain, spinal cord, other organs potentially infected with BSE) (Ockerman and Hansen, 2000). More recent infectious disease outbreaks, such as avian influenza and severe acute respiratory syndrome, have further jeopardized diplomatic relations, frightened the public, and caused massive economic losses by disrupting global commerce (Karesh and Cook, 2005). Since then, concern over the risks posed by ABPs, including infectious diseases (such as swine fever, foot and mouth) and other contaminants (such as dioxins), to human and animal health, has resulted in strict regulations regarding their safe handling and disposal (Cunningham, 2003; Department for Environment Food and Rural Affairs, 2011). As such, most countries now have local regulations put in place that are typically broad in scope and directly affect any person or business that

generates, uses, disposes, stores, handles, or transports food waste containing animal products and ABPs derived from the food processing industry.

Currently, most countries no longer allow animal by-product meals containing any amount of ruminant tissue to be fed to other ruminant animals, although meat and bone meals containing ruminant tissue are still able to be fed to nonruminant animals, such as poultry, swine, pets, and aquaculture species in most countries, including New Zealand (Garcia and Phillips, 2009). To the contrary, throughout the European Union, meat and bone meals are banned from the feed of any animal that may become human food, and as a result, in the European Union, meat meal and meat and bone meal are primarily incinerated or used as an ingredient in pet food (Kirchmayr et al., 2007).

In most countries, legislation for waste disposal and disposal of dead animals and of slaughterhouse materials (animal rendering) is already in place. In Germany, the Animal Disease Act, the Meat Hygiene Act, the Poultry Meat Act, and the Meat Hygiene Ordinance also regulate the disposal of slaughterhouse offal. To protect animal and human health, the Canadian Food Inspection Agency (CFIA) enforces federal regulations governing the production and use of rendered materials that may be used in animal feed. However, a policy established by the National Renderers Association, which prevented ovine material (sheep) from being used in meat and bone meals in the United States and Canada, and has been withdrawn (Malone, 2005).

Compared to Canadian and US policy, the framework of the EU regulations regarding ABPs and derived products is complex, resulting from ongoing reviews by the EU Commission. Each updated regulation is a result of the successive amendment to the initial Regulation (EC) 1774/2002, most recently amended with (EU) No. 749/2011. The regulation covers the safe disposal

options available for all animal products, including meat, fish, milk, and eggs not intended for human consumption, and other products of animal origin, including hides, feathers, wool, bones, horns, and hooves. It also prohibits catering waste being used as livestock feed and covers disposal of fallen stock, companion animals, and wild animals if they are suspected of being diseased. The regulations also control the use of ABPs as feed, fertilizer, and technical products with rules for their transformation via composting and biogas operations and their disposal via rendering and incineration (Department for Environment Food and Rural Affairs, 2011).

6 CURRENT MANAGEMENT OPTIONS

When looking at the existing options available for management of these by-products (and/or wastes), both legal regulations and the best ecological and economical solutions need to be considered. Whether a material is deemed to be a valuable by-product (or a waste that needs to be disposed of) depends on the social, legal, and technological framework surrounding its origin. From there, the most sensible form of management becomes a compromise between what is viewed as acceptable, based on legal requirements and local perceptions, and what is technologically and financially feasible (Fig. 1.3).

Although it is most desirable to prevent waste and by-product formation, followed by reuse or recycling into other product lines, the formation of by-products and waste is inevitable, and management options must be innovative and also meet local regulatory requirements. Waste management is then possible through several media: to use it in its current form, dispose of it through incineration or landfill, or add value to it through bioprocessing or valorization technologies (Fig. 1.4). The choice of media used will largely depend on the cost, customs, and regulatory environment. For example,

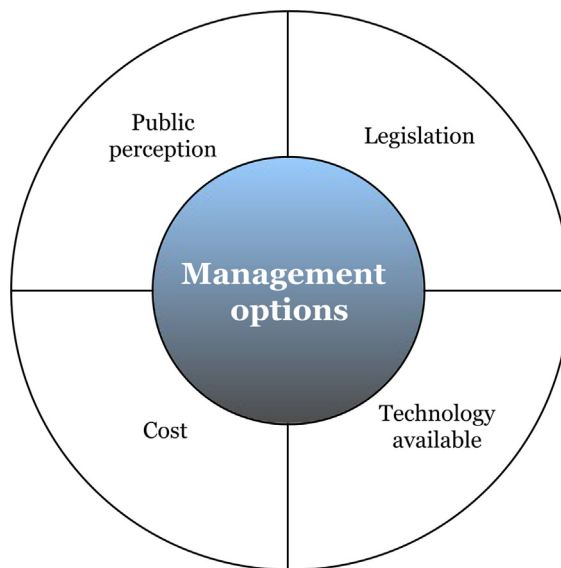


FIGURE 1.3 Forming a sensible waste management system relies on compromise between public perception, legislation, cost, and technologies.

converting the by-product to animal fodder (bio-reduction) may not be feasible in all countries.

Excess and waste food has been used as animal fodder for centuries, and in many parts of the world, farmers still use waste food to feed their animals—primarily pigs and poultry. The practice of feeding waste material containing meat products to pigs was banned in the United Kingdom in 2001 (Statutory Instrument 2001, No. 1704 The Animal By-products Amendment) to prevent further spread of BSE, and soon after, a new regulation was implemented throughout the European Union (The Animal By-Products Regulation, EC No: 1774/2002) prohibiting catering waste from being fed to farmed animals. This includes all waste food and used cooking oils, as well as waste from vegetarian restaurants and kitchens. Based on these laws, only certain types of waste food can be given to livestock and must first be treated appropriately.

If the by-product cannot be immediately used as it is or treated appropriately for use as an animal feed, it must be safely disposed of.

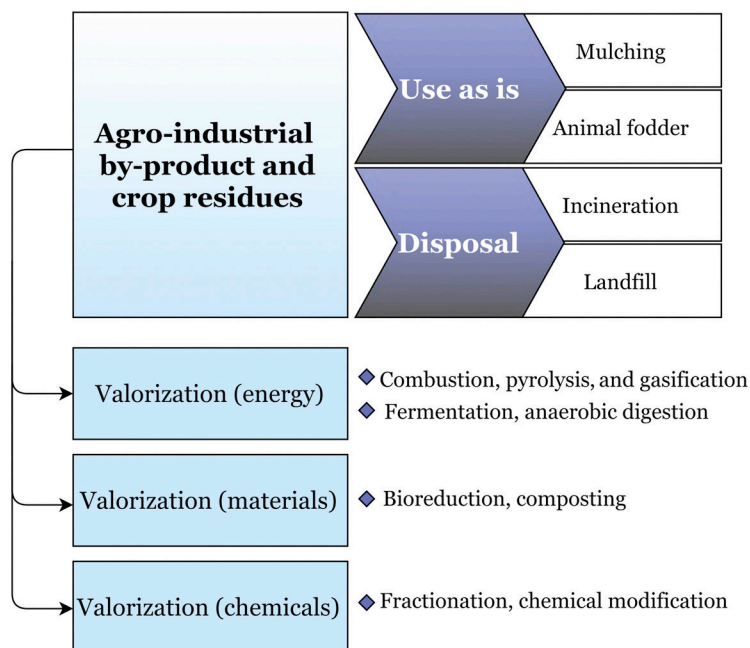


FIGURE 1.4 Flow diagram for conversion of agro-industrial by-products and crop residues.

Because of the time and expense of treating these food wastes, most end up in landfill. Currently, landfilling and incineration account for the treatment of greater than 95% of food waste in most European countries (Melikoglu et al., 2013). In general, using the biomass waste in the form it is in, either as an animal feed or fertilizer or as a fuel to generate electricity, is the most simplistic approach and generates a value of ~US\$70–200 per metric ton of biomass (Tuck et al., 2012).

6.1 Incineration

Incineration is the simplest means of waste disposal, with its major advantage being the significant reduction in volume of the waste stream, which is up to 90% for waste streams with high amounts of paper, cardboard, plastics, and horticultural waste (Hoornweg and Bhada-Tata, 2012). However, most food wastes are not appropriate for incineration, owing to their high moisture content. When properly equipped, an

incinerator can be used as a means of energy recovery to generate electricity. Heat released from the combustion of waste can be used to produce steam, which can turn a steam turbine, generating electricity. However, because of the increased concentration of toxins in the ash, incinerators must be operated alongside landfill systems in order to dispose of them. Combustion destroys chemical compounds and disease-causing bacteria, leaving it pathogen free, but causes serious environmental problems through the production of carbon dioxide, nitrogen oxides, sulfur dioxide, and trace quantities of toxic pollutants, such as heavy metals and dioxins. The remaining residues are often landfilled, owing to their high heavy metal content.

6.2 Pyrolysis and Gasification

Thermochemical conversion of food and industry wastes are an effective means of converting energy-rich biomass into a more easily used

liquid or gaseous intermediate. High temperatures can be used with minimal (gasification) or no oxygen present (pyrolysis) to break down hydrocarbon containing wastes, resulting in combustible syngas mixtures, containing carbon monoxide and hydrogen (85%), with small amounts of carbon dioxide and methane. This syngas intermediate can be further processed to produce bio-based gasoline, diesel, or jet fuel, or be used in a fuel cell to generate electricity or steam.

6.3 Landfilling

Landfills—burying the material—are a common final disposal site for waste and the residues remaining from other treatment options. At atmospheric pressure, 1 metric ton of organic material generates approximately 200–500 m³ of landfill gas over a 10–20 year timeframe (Jardine et al., 2004), comprised of 60–65 % methane and 35–40 % carbon dioxide, which represents around 8% of the anthropogenic methane (CH₄) emitted worldwide (Melikoglu et al., 2013). Methane has 21 times the global warming potential of carbon dioxide and can be recovered and burned (with or without energy recovery) to reduce greenhouse gas emissions (Hoornweg and Bhada-Tata, 2012). Other serious environmental implications of landfilling include the risk of leachate (potential toxic liquid that drains from landfills) entering surrounding soils and groundwater.

Although the use of landfills is common, their use has been discouraged through the implementation of landfill taxes and directives, such as the UK “Landfill Tax” in 1996 and EU Landfill Directive established in 1999 (Jardine et al., 2004). Obviously, other disposal options are preferred to landfilling, which costs ~US\$400 per metric ton.

6.4 Bioprocessing

Around 60% of the municipal waste sent to landfill is biodegradable and mostly comprised of food waste (Hoornweg and Bhada-Tata, 2012). This makes bioprocessing, such as composting

and anaerobic digestion, sensible options for disposing of these organic waste streams.

A common means of obtaining a safe end product is achieved through composting. This involves a combination of chemical and microbiological processes occurring throughout three stages that convert organic materials to a stable, soil-like product called *compost* (Som et al., 2009; Verbeek et al., 2012). Provided composting is carried out well, the volume and mass of the waste can be reduced by up to 40%. For composting to occur efficiently, the conditions of the composting process must be maintained at an optimal level to encourage microbial growth. Because of changes in the composition of waste material with location and over time, the compost mixture needs optimization through regular adjustments. For example, if the system becomes anaerobic, offensive odors can be produced, and if it becomes too wet or too dry, the process will halt altogether. Some of these organic waste materials require specific pretreatment before composting can occur. In the United Kingdom, EU standards must be implemented over and above UK standards if the site treats category 2 ABPs, which have first been pressure rendered, or category 3 ABPs if they exclude catering waste. Exceptions apply for some types of ABPs in the United Kingdom, which can be composted in closed reactors at 70°C for more than 1 h or in housed rows of piled green-waste (windrows) at 60°C for more than 8 days under strict operating parameters with a maximum particle size of 400 mm.

Although compost is of limited value, it is still a more economic option compared to landfilling. Other bioprocesses can be employed that produce more valuable products. Biofuels can be produced using fermentation, valued at US\$ 200–400 per metric ton more than the initial biomass waste (Tuck et al., 2012). Anaerobic digestion is another means of disposing of organic waste materials and is carried out in an enclosed vessel. The methane generated can either be flared or collected for combustion to generate heat and/or electricity, which also adds value to the waste biomass.

The maximum value can be recovered from these waste materials by converting them into more purified streams and using them in the manufacture of lubricants, surfactants, plastics, fibers, and industrial solvents. Theoretically, all ABPs in the European Union could be combusted as fuel for energy, provided the EU Commission formulates the appropriate rules and regulations, which as of yet has not been done.

Although there are many technologies currently available (or in developmental stages) that aim to valorize by-products of industry, legislation has yet to be passed that explicitly deals with higher technology outcomes. Most current law deals with the safe handling and disposal of animals, their products, and by-products and animal feeding. Although it is necessary to contain health and environmental risks through appropriate legislation, it is becoming apparent that the use of ABPs and food wastes (excluding crop residues and some agro-industrial by-products) for animal fodder and composting is not only obsolete, but in many nations, illegal.

7 VALUE ADDITION

Many technologies exist that aim to valorize by-products of the agricultural industry. Although the edible portion of these protein-rich by-products could be used for recovery of essential amino acids for human consumption, or as is for use in animal feeds, higher value applications for inedible and nonessential amino acids may include providing a feedstock for protein-based materials, such as plastics, and for the production of biopesticides and commodity organic compounds (Naik et al., 2010; Scott et al., 2007).

Along with more obvious uses of protein hydrolysates—animal feeds and biomass for energy recovery—protein-based meals from crop residues and agro-industrial by-products also find value addition through use in biological processes. An example is the use of various oilseed cakes, which have been shown to

be ideal mediums for many types of bacteria and fungi responsible for producing a variety of enzymes, antibiotic and antimicrobial compounds, and bioactive metabolites (Ramachandran et al., 2007). Protein-based raw materials can be used for the production of 1,2-ethanediamine and 1,4-butanediamine from the amino acids serine and arginine, respectively (Sanders et al., 2007). Furthermore, protein-based surfactants are valuable mild surfactants, because the structure and properties of the amino acids in the surfactants are similar to the amino acids that make up the tissue of skin.

If valorization technologies are to be implemented on a commercial scale, they must work within current legal constructs. However, this does not deal directly with the science involved and may inhibit progress if new legislation is not developed that more closely examines the evidence and whether risk regarding human and animal health is still an issue. In light of current legislation and potential markets for value-added commodities, it is becoming apparent that the use of protein-rich agricultural by-products for lower value applications, such as animal fodder, is no longer a sensible use of such a valuable resource.

LIST OF ABBREVIATIONS

ABP	Aanimal by-product
BSE	Bovine spongiform encephalopathy
CFIA	Canadian Food Inspection Agency
EC	European Commission
EU	European Union
UK	United Kingdom
US	United States

References

- Adeola, O., 2003. Energy values of feed ingredients for white pekin ducks. *Int. J. Poultry Sci.* 2 (5), 318–323.
- Agunbiade, J.A., Susenbeth, A., Sudekum, K.H., 2004. Comparative nutritive value of cassava leaf meal, soya beans, fish meal and casein in diets for growing pigs. *J. Anim. Physiol. Anim. Nutr.* 88 (1–2), 30–38.
- Anongu, A.A., Joseph, J.K., 2008. Proximate analysis of castor seeds and cake. *J. Appl. Sci. Environ. Manage.* 12 (1), 39–41.

- Ash, M.S., 1992. *Animal Feeds Compendium*. United States Department of Agriculture, Washington, DC.
- Association of American Feed Control Officials, 2007. *Official Publication: Association of American Feed Control Officials*. Cornell University Press, USA.
- Bimbo, A.P., 2000. Fish meal and oil. In: Martin, R.E., Carter, E.P., Flick, G.J.J., Davis, L.M. (Eds.), *Marine and Freshwater Products Handbook*. Technomic, Pennsylvania, 541–482.
- Chen, S., Harrison, J.H., Liao, W., Elliot, D.C., Liu, C., Brown, M.D., Wen, Z., Solana, A.E., Kincaid, R.L., Stevens, D.J., 2003. Value-Added Chemicals from Animal Manure. Pacific Northwest National Laboratory, United States Department of Energy, Washington, DC.
- Chu, Z.J., Yu, D.H., Yuan, Y.C., Qiao, Y., Cai, W.J., Shu, H., Lin, Y.C., 2015. Apparent digestibility coefficients of selected protein feed ingredients for Loach *Misgurnus anguillicaudatus*. *Aquacult. Nutr.* 21 (4), 425.
- Cunningham, E.P., 2003. *After BSE: A Future for the European Livestock Sector*. Wageningen Academic, Gelderland, The Netherlands.
- de las Fuentes, L., Sanders, B., Lorenzo, A., Alber, S., 2004. *Awarenet: Agro-Food Wastes Minimisation and Reduction Network*. In: Waldron, K., Faulds, C., Smith, A. (Eds.), *Total Food: Exploiting Co-Products—Minimizing Wastes: Proceedings*. Institute of Food Research, Norwich, England.
- Department for Environment, Food and Rural Affairs, 2011. *Controls on Animal By-Products: Guidance on Regulation (EC) 1069/2009 and Accompanying Implementing Regulation (EC) 142/2011, Enforced in England by the Animal By-Products (Enforcement) (England) Regulations 2011*. Department for Environment, Food and Rural Affairs, London.
- El-Saidy, D.M.S.D., Gaber, M.M.A., 2003. Replacement of Fish Meal with a Mixture of Different Plant Protein Sources in Juvenile Nile Tilapia, *Oreochromis niloticus* (L.) Diets. *Aquacult. Res.* 34 (13), 1119–1127.
- El-Saidy, D.M.S.D., Saad, A.S., 2008. Evaluation of Cow Pea Seed Meal, *Vigna Sinensis*, as a Dietary Protein Replacer for Nile Tilapia, *Oreochromis niloticus* (L.), Fingerlings. *J. World Aquacult. Soc.* 39 (5), 636–645.
- Everts, H., Nguyen, L.Q., Beynen, A.C., 2003. Shrimp by-product feeding and growth performance of growing pigs kept on small holdings in Central Vietnam. *Asian-Australas. J. Anim. Sci.* 16 (7), 1025–1029.
- Fanimo, A.O., Oduguwa, O.O., Onifade, A.O., Olutunde, T.O., 2000. Protein quality of shrimp-waste meal. *Bioreour. Technol.* 72 (2), 185–188.
- Fanimo, A.O., Susenbeth, A., Südekum, K.H., 2006. Protein utilisation, lysine bioavailability and nutrient digestibility of shrimp meal in growing pigs. *Anim. Feed Sci. Tech.* 129 (3–4), 196–209.
- Foley, J.A., 2011. Can we feed the world and sustain the planet? A five-step global plan could double food production by 2050 while greatly reducing environmental damage. *Sci. Am.* 305, 60–65.
- Food and Agriculture Organization of the United Nations, 2011. *Global Food Losses and Food Waste—Extent, Causes and Prevention*. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Food and Agriculture Organization of the United Nations, 2013. *Production Quantity 2013*. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Fuller, G., Walker, Jr., H.G., Mottola, A.C., Kuzmicky, D.D., Kohler, G.O., Vohra, P., 1971. Potential for detoxified castor meal. *J. Am. Oil Chem. Soc.* 48 (10), 616–618.
- Garcia, R.A., Phillips, J.G., 2009. Physical distribution and characteristics of meat and bone meal protein. *J. Sci. Food Agric.* 89 (2), 329–336.
- Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010a. Food security: the challenge of feeding 9 billion people. *Science* 327 (5967), 812–818.
- Godfray, H.C.J., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Nisbett, N., Pretty, J., Robinson, S., Toulmin, C., Whiteley, R., 2010b. The future of the global food system. *Philos. Trans. R. Soc. London, Ser. B.* 365 (1554), 2769–2777.
- Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A., 2011. *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Hardy, R.W., Tacon, A.G.J., 2002. Fish meal: historical uses, production trends and future outlook for sustainable supplies. In: Stickney, R.R., McVey, J.P. (Eds.), *Responsible Marine Aquaculture*. CABI, London.
- Haughey, D.P., 1976. *Market Potential and Processing of Blood Products: Some Overseas Observations*. In: MIRINZ series, vol. 535. Meat Industry Research Institute of New Zealand (MIRINZ), Hamilton, New Zealand.
- Hoonweg, D., Bhada-Tata, P., 2012. *What a waste: a global review of solid waste management*. Urban Development Series Knowledge Papers, vol. 12. World Bank, Washington, DC.
- Hornsby, D.J., 2013. *Risk Regulation, Science, and Interests in Transatlantic Trade Conflicts*. International Political Economy Series. Palgrave Macmillan, London.
- Howie, S.A., Calsamiglia, S., Stern, M.D., 1996. Variation in ruminal degradation and intestinal digestion of animal by-product proteins. *Anim. Feed Sci. Tech.* 63 (1–4), 1–7.
- Jardine, C.N., Boardman, B., Osman, A., Vowles, J., Palmer, J., 2004. *Methane UK, research report 30*. Environmental Change Institute, University of Oxford, Oxford, UK.
- Kaluzny, D., 2013. *World Renderers Organization: Rendered Products Worldwide*. Global Feed & Food Congress, Sun City, South Africa.

- Kamalak, A., Canbolat, O., Gurbuz, Y., Ozay, O., 2005. In situ ruminal dry matter and crude protein degradability of plant- and animal-derived protein sources in Southern Turkey. *Small Ruminant Res.* 58 (2), 135–141.
- Karesh, W.B., Cook, R.A., 2005. The human-animal link. *Foreign Affairs*. Available from: <<http://www.foreignaffairs.com/articles/60821/william-b-karesh-and-robert-a-cook/the-human-animal-link>>.
- Kassahun, A., Waidbacher, H., Zollitsch, W., 2012. Proximate composition of selected potential feedstuffs for small-scale aquaculture in Ethiopia. *Livestock Res. Rural Dev.* 24 (6), Available from: <http://www.lrrd.org/lrrd24/6/kass241106.htm>.
- Khanum, S.A., Yaqoob, T., Sadaf, S., Hussain, M., Jabbar, M.A., Hussain, H.N., Kausar, R., Rehman, S., 2007. Nutritional evaluation of various feedstuffs for livestock production using in vitro gas method. *Pak. Vet. J.* 27 (3), 129–133.
- Kirchmayr, R., Resch, C., Mayer, M., Prechtl, S., Faulstich, M., Braun, R., Wimmer, J., 2007. Anaerobic degradation of animal by-products. In: Oreopoulou, V., Russ, W. (Eds.), *Utilization of By-Products and Treatment of Waste in the Food Industry*. Springer, New York, pp. 159–192.
- Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., Ward, P.J., 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Sci. Total Environ.* 438 (0), 477–489.
- Lefferts, L., Kucharski, M., McKenzie, S., Walker, P., 2006. *Feed for Food-Producing Animals: A Resource on Ingredients, the Industry, and Regulation* vol. 115. Bloomberg School of Public Health, The Johns Hopkins Center for a Livable Future, Baltimore, pp. 663–670.
- Leoci, R., 2014. *Animal By-Products (ABPs): Origins, Uses and European Regulations*. Universitas Studiorum, Mantova, Italy, pp. 15–21.
- Malone, J., 2005. NRA rescinds sheep material policy. *American Sheep Industry Association, ASI Weekly*. ASIA, Colo, IA.
- Martínez-Llorens, S., Vidal, A.T., Moñino, A.V., Gómez Ader, J., Torres, M.P., Cerdá, M.J., 2008. Blood and haemoglobin meal as protein sources in diets for gilthead sea bream (*Sparus aurata*): effects on growth. *Aquacult. Res.* 39 (10), 1028–1037.
- Maye, D., Dibden, J., Higgins, V., Potter, C., 2012. Governing biosecurity in a neoliberal world: comparative perspectives from Australia and the United Kingdom. *Environ. Plann. A.* 44, 150–168.
- Melikoglu, M., Lin, C.S.K., Webb, C., 2013. Analysing global food waste problem: pinpointing the facts and estimating the energy content. *Cent. Eur. J. Eng.* 3 (2), 157–164.
- Mills, P., Dehnen-Schmutz, K., Ilbery, B., Jeger, M., Jones, G., Little, R., MacLeod, A., Parker, S., Pautasso, M., Pietravalle, S., Maye, D., 2011. Integrating natural and social science perspectives on plant disease risk, management and policy formulation. *Philos. Trans. R. Soc. London, Ser.*, 366, 2035–2044.
- Msangi, S., Rosegrant, M.W., 2011. Feeding the future's changing diets: implications for agriculture markets, nutrition, and policy. Paper presented at the International Food Policy Research Institute Conference: Leveraging Agriculture for Improving Nutrition and Health, New Delhi, India.
- Murray, S., 2007. The world's biggest industry. *Forbes*. Available from: <http://www.forbes.com/2007/11/11/growth-agriculture-business-forbeslife-food07-cx_sm_1113bigfood.html>.
- Naik, S.N., Goud, V.V., Rout, P.K., Dalai, A.K., 2010. Production of first and second generation biofuels: a comprehensive review. *Renew. Sustainable Energy Rev.* 14 (2), 578–597.
- National Research Council, 2001. *Nutrient Composition of Feeds*, seventh rev. ed. The National Academies Press, Washington, DC, pp. 281–314.
- National Research Council and Canadian Department of Agriculture, 1971. *Atlas of Nutritional Data on United States and Canadian Feeds*. National Academy of Sciences, Washington, DC.
- Nengas, I., Alexis, M.N., Davies, S.J., Petchakis, G., 1995. Investigation to determine digestibility coefficients of various raw materials in diets for gilthead sea bream, *Sparus auratus* L. *Aquacult. Res.* 26 (3), 185–194.
- Ockerman, H.W., Hansen, C.L., 2000. Rendering. In: Ockerman, H.W., Hansen, C.L. (Eds.), *Animal By-Product Processing and Utilization*. CRC Press, Boca Raton, FL, pp. 87–126.
- Okoye, F.C., Ojowola, G.S., Njoku-Onu, K., 2005. Evaluation of shrimp waste meal as a probable animal protein source for broiler chickens. *Int. J. Poultry Sci.* 4 (7), 458–461.
- Pimentel, D., Pimentel, M., 2003. Sustainability of meat-based and plant-based diets and the environment. *Am. J. Clin. Nutr.* 78 (3), 660–663.
- Pleissner, D., Lin, C., 2013. Valorisation of food waste in biotechnological processes. *Sustainable Chem. Processes.* 1 (1), 1–6.
- Pousga, S., Boly, H., Lindberg, J.E., Ogle, B., 2007. Evaluation of traditional sorghum (*Sorghum bicolor*) beer residue, shea-nut (*Vitellaria paradoxa*) cake and cottonseed (*Gossypium spp*) cake for poultry in Burkina Faso: availability and amino acid digestibility. *Int. J. Poultry Sci.* 6 (9), 666–672.
- Preston, R.L., 2014. *Feed Composition Table, 2014*. Penton Media, Minneapolis, pp. 18–26.
- Qiao, S., Thacker, P.A., 2004. Use of the mobile nylon bag technique to determine the digestible energy content of traditional and non-traditional feeds for swine. *Arch. Anim. Nutr.* 58 (4), 287–294.
- Ramachandran, S., Singh, S.K., Larroche, C., Soccol, C.R., Pandey, A., 2007. Oil cakes and their biotechnological applications—a review. *Bioresour. Tech.* 98 (10), 2000–2009.

- Sanders, J., Scott, E., Weusthuis, R., Mooibroek, H., 2007. Biorefinery as the bio-inspired process to bulk chemicals. *Macromol. Biosci.* 7 (2), 105–117.
- Santana-Méridas, O., González-Coloma, A., Sánchez-Vioque, R., 2012. Agricultural residues as a source of bioactive natural products. *Phytochem. Rev.* 11 (4), 447–466.
- Scarlat, N., Martinov, M., Dallemand, J., 2010. Assessment of the availability of agricultural crop residues in the European Union: potential and limitations for bioenergy use. *Waste Manage.* 30 (10), 1889–1897.
- Scott, E., Peter F., Sanders, J., 2007. Biomass in the manufacture of industrial products—the use of proteins and amino acids. *Appl. Microbiol. Biotechnol.* 75 (4), 751–762.
- Som, M., Lemée, L., Amblès, A., 2009. Stability and maturity of a green waste and biowaste compost assessed on the basis of a molecular study using spectroscopy, thermal analysis, thermodesorption and thermochemolysis. *Bioresour. Technol.* 100 (19), 4404–4416.
- Swisher, K., 2013. Market Report: US Rendering: A \$10 Billion Industry. *Rendering Magazine*.
- Trushenski, J., Gause, B., 2013. Comparative value of fish meal alternatives as protein sources in feeds for hybrid striped bass. *North Am. J. Aquacult.* 75 (3), 329–341.
- Tuck, C.O., Pérez, E., Horváth, I.T., Sheldon, R.A., Poliakoff, M., 2012. Valorization of biomass: deriving more value from waste. *Science* 337 (6095), 695–699.
- United States Department of Agriculture, 2013. *Agricultural Statistics*. United States Department of Agriculture, Washington, DC.
- United States Department of Agriculture, 2015a. *World Agricultural Supply and Demand Estimates*. United States Department of Agriculture, Washington, DC.
- United States Department of Agriculture, 2015b. *Oil crops outlook*. United States Department of Agriculture, Washington, DC.
- United States Department of Commerce, 1994. *Current industrial reports: manufacturing profiles 1992*. Economics and Statistics Administration, Bureau of the Census Editors, United States Department of Commerce, Washington, DC.
- van Huis, A., 2013. Potential of insects as food and feed in assuring food security. *Annu. Rev. Entomol.* 58 (1), 563–583.
- Verbeek, C.R., Hicks, T., Langdon, A., 2012. Biodegradation of bloodmeal-based thermoplastics in green-waste composting. *J. Polym. Environ.* 20 (1), 53–62.
- Wiedemann, S., Yan, M., 2014. *Livestock meat processing: inventory data and methods for handling co-production for major livestock species and meat products*. Paper presented at the Ninth International Life Cycle Assessment of Foods Conference, San Francisco.
- Wiener, J., 2011. The real pattern of precaution. In: Wiener, J., Rogers, M., Hammitt, J., Sand, P. (Eds.), *The Reality of Precaution: Comparing Risk Regulation in the US and Europe*. Earthscan, New York.