TITLE: Animal by-products for feed: characteristics, European regulatory framework, and potential impacts on human and animal health and the environment

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Animal by-products for feed: characteristics, European regulatory framework, and potential impacts on human and animal health and the environment

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ABSTRACT. Animal by-products (ABPs), such as processed animal proteins, animal fats, milk and egg products, and former food products represent a potentially valuable resource for feeding livestock. According to Europe's authorities, around 18 million t of animal fat and meat industry by-products arise annually in the European Union (EU) from slaughterhouses, dairies and plants producing food for human consumption. Another 8 to 12 million t emerge every year as former foodstuffs. Recycling of slaughter by-products and other animal products, sometimes considered as waste materials, into animal feed can bring major benefits to the economics of livestock production and the environment in the EU. Nevertheless, improper and unregulated use of ABPs and food waste, as could be noticed from a number of food crises in the recent past, have a strong public health and economic impact. For a safety reasons most ABP materials have been subject to severe restrictions in their use for feed farm animals in the EU. However, due to the decreasing risk of transmissible spongiform encephalopathies, important positive changes of animal by-product processing industry in Europe and developing validated diagnostic methods to test for species-specific material in feed, the European Commission started to reform these stringent rules, thus non-ruminant processed animal proteins has been authorized in aqua feed starting from 1 June 2013. The aim of this review is to describe the status of ABPs in the feed industry, to identify new opportunities, and to place these residue materials in the framework of the EU legislation for safety.

KEYWORDS: animal, feeding, feed safety, former foodstuffs

Introduction

The ingredients used in livestock feeding are fundamentally important in terms of both the quality of resulting food products and potential human health effects among consumers (Sapkota et al., 2007). Animal feed is often used to recycle by-products of the food manufacturing and food waste. A number of organic residual materials have adequate, some even very high, nutritional value and they can be fed to farm animals as a competitive alternative to traditional feedstuffs and/or valuable supplements. Between 32 and 48% (Table 1) of the weight of food-producing animals is removed during slaughter and further meat processing (Alm, 2012a). Aforementioned residue materials represent a category of animal by-products (ABPs) and include parts of animal that we do not normally eat, such as fat trims, meat viscera, blood, bones, feathers, hides and skins. Additionally, out of date food products i.e. former foodstuffs (FF) no longer meant for human consumption, which may contain ingredients of animal origin (fat, milk, eggs and gelatine) can be also classified as ABPs. Therefore, ABPs comprise materials and products originated from food-producing animals not intended for people consumption, however they can be recycled to other purposes, such as animal feed, organic fertilizers and soil improvers, technical products for leather or chemical industry.

Currently, a very limited number of animal residues and derived products can be legally recycled to livestock feed in the European Union (EU) i.e. only low risk category 3 ABP material, including FF not containing meat and fish. Animal by-products, as defined by the EU legislation, require rendering process before subsequent use in farm animal feed, with the exception of eligible former foods (GOV.UK, 2014a). The processing methods have to ensure feed safety by applying conditions that cause killing of pathogenic microorganisms and guarantee chemical quality of products, and mainly engage a heat treatment or unwrapping in case of former food products. In general, ABPs represent an economical sources of important nutrients for livestock in easy digestible form, particularly protein comprising all essential amino acids, energy in the form of fats and carbohydrates, vitamins and minerals, mainly phosphorus and calcium. However, due to the lack of authorization for feed use of some ABP materials in the EU, such as processed animal proteins (PAPs) from non-ruminants, they are utilized in other allowed ways (fertilizers and energy purpose) so their maximum nutritional potential cannot be achieved. Furthermore, in some EU member states, mainly in New Member States, former foodstuffs still often end up rotting in landfill, where they release methane which has a negative effect on the environment, contributing to a greenhouse effect.

Feed cost is the largest expense in farm animal production in Europe, mainly due to the need for imported protein ingredients (soyabean and fish meal), and may be reduced by increasing a home-production of protein-rich feed sources. According to European Fat Processors and Renderers Association (EFPRA) Europe's protein production covers only around 30% of the consumption (Feedinfo, 2014). This change can bring many positive effects on farming, including an increase in the profit margin of livestock producers, ensured regular supply of an economical sources of protein and energy, moderation of the price for competing nutrient sources (soyabean meal), decrease in an environmental and financial costs of sourcing mined phosphorus and the need to farm marginal lands for additional protein-rich crops.

Although the by-product feeds can be available at reasonable price, other factors such as nutrition value, palatability, possible contamination with pathogenic microbes or chemicals, and the effects on digestion, must also be carefully considered. A number of food crises in the recent past, which concerned an outbreaks of some notifiable animal diseases (classical swine fever, avian influenza, bovine spongiform encephalopathy (BSE)) or contamination with chemicals (dioxins), showed that unregulated and improper use of rendered animal products and food waste can have strong economic impact and seriously affect the safety of public health. It might seem that the simplest solution to ensure the safety of animal and human health is to introduce the total ban on the use of these materials, however it is not an option at all as we make an economic use of many products and by-products sourced from animals, such as laboratory reagents, feed material, pet-food, furnishings, soil improvers and biogas. Therefore, the best option is to establish an appropriate level of protection through comprehensive EU feed and food strategy, stringent animal health control measures, quality management systems for feed and food manufacturers, such as Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Points (HACCP), and alert systems, such as Rapid Alert System for Food and Feed (RASFF), so beneficial uses of these materials can continue safely. Legislation has been in place for many years to control potential risks associated with feed use of rendered animal products and food waste. The use of ABPs in farm animal feed is extensively regulated by the EU legislation, including Regulation 1069/2009 and Regulation 142/2011 (ABP Regulations), Regulation 999/2001 (TSE Regulation) and Regulation 183/2005 on feed hygiene.

This review focuses on the use of ABPs as animal feed ingredients across the EU. Issues addressed include of a nutritive characterization of main ABPs, their feasibility for use as feedstuffs, EU legislation on their recycling, use in animal feeds, and feed safety, their current management, and methods of processing.

Current EU legislation and future prospects on the use of ABPs in farm animal feeding

The management of ABPs and derived products, due to safety reasons, is strictly regulated by European legislation. Regulation governing in comprehensive way the control of animal residues (Animal By-Products Regulation) had been introduced at the beginning of the twenty-first century. Initially it was Regulation 1774/2002 which is actually repealed by Regulation 1069/2009 and accompanying Regulation 142/2011. To prevent ABPs presenting a risk to humans, animals and the environment the ABP Regulation lays down rules for the collection, transport, storage, handling, processing, and placing on the market, import, export and transit of raw ABPs and products derived from them (Farrar, 2010). The EU regulations are amongst the most stringent in the world. ABPs are classified into three categories by the risks they pose and the methods used to deal with them. Category 1 is for the highest risk material, and comprises principally animal residue that is considered a transmissible spongiform encephalopathy (TSE) risk or infected with diseases communicable to humans or animals, or products from animals containing contaminants, such as pesticides, heavy metals and dyes at above permitted levels. Material of category 2 is also high risk and includes ABPs containing excess residues of specific drugs, such as antibiotics, and also import products that failed vet control, animals killed or died outside the human food chain, manure and certain products from slaughterhouses. Category 3 materials are of a low risk i.e. do not provide a direct threat to humans and animals, and among them are placed parts of animals that have been passed fit for human consumption in a slaughterhouse but are not intended for people consumption, either because they are not parts of animals that we normally eat (hides, horns, hair, feathers and bones) or for commercial reasons. This category includes also former foodstuffs, and catering waste, and kitchen waste. The legal ways of disposal and use of each category ABP material are considerably different, and briefly presented in Table 2.

The ABP Regulation establishes also some general restrictions on recycling the ABPs into livestock feed, such as ban on feeding farm animals with catering/household waste and processed protein from bodies of animals of the same species, and authorization for FF only containing milk and egg products, fats or gelatine from non-ruminants to be fed to food-producing animals. Additionally, only ABPs and derived products that have been collected and processed in accordance with appropriate conditions, and come from an approved and registered, by governmental agencies and/or local authorities, rendering plants or food processing facilities can be placed on the market as products destined for feed. In case of slaughterhouse by-products of category 3 the time and temperature (between 80 and 133 °C) combinations, depending on the particle size (between 20 and 150 mm in width and height), are required in the rendering process (GOV.UK, 2014b). These are sufficient conditions to kill pathogenic bacteria, viruses and other microorganisms, resulting in protein product that is free of potential biohazards and environmental threats (Figure 1). Risks of animal and human exposure to biological hazards are found to be negligible when ABPs are processed by rendering industry. Materials that fall under Regulation 1069/2009 are subject to traceability requirements from the point they enter into its scope and until their final use. Therefore, rendering can be suitable, particularly for governmental agencies, to trace ABP material back to the source and the finished products forward to their disposal and use. These are important factors when attempting to prevent, control or eradicate any notifiable disease (Hamilton et al., 2006). Former foodstuffs regarded as low risk i.e. containing only animal ingredients such as milk and egg products, fats and oils, and gelatine from non-ruminants, and providing they have not been in contact with raw meat or fish, can be used for feed purpose without further ABP specific processing, as required for slaughter waste. Non wrapped food items, including non-packed confectionary products and bread, are fit for direct feed use, whilst wrapped or moist food require processing, which in general means unwrapping, drying, extraction, extrusion or smoking. However, a big challenge in practice to compliance with feed safety standards can be technical impossibility towards complete removal of the packaging during unwrapping process. Best available techniques enable reduction in the amount of packaging down to 0.15% (FEFAC, 2012). The establishments that place former foodstuffs on the feed market have to be registered as feed business operators under Feed Hygiene Regulation (Regulation 183/2005), and also FF processors are subject to approval under the same legislation.

Rendered category 3 ABP material can be used in the production of livestock feedstuffs, though other restrictions, mainly TSE related, on the feeding of animal proteins severely restrict this. The feed ban on the use of PAP in feed for farmed animals is the basic preventive measure against the transmission of BSE. It was introduced in the EU in 1994 in reaction to the poor control of meat and bone meal (MBM) in the animal feed chain during the 1980's and 1990's. The ban referred to the feeding of mammalian processed animal protein to ruminants (cattle, sheep and goats) only, however was expanded in January 2001 (Regulation 999/2001) to all farmed animals (TSE/BSE – Feed Ban, 2015). Regulation 999/2001 (TSE Regulation) prohibited the feeding of most animal proteins to ruminants, with a few exceptions including milk and egg products; and also the feeding of processed animal protein (MBM and gelatine of ruminant origin) to all farmed animals; and restricted a small number of proteins i.e. fishmeal, blood products, di-calcium/tri-calcium phosphate of animal origin to be fed to non-ruminants (pigs and poultry) only (GOV.UK, 2015).

However, due to an ever decreasing risk of TSEs throughout Europe and scientific opinions which found no TSE risk occurring from the provision of PAP from non-ruminants to non-ruminant animals (providing that intra-species recycling is prevented), together with estimated Europe's 70% protein deficit (Häusling, 2011), it was necessary to reform the stringent rules on the use of animal proteins in feed. Furthermore, validated analytical test based on PCR assay on ruminant constituents in feed and PAPs was successfully developed by European Reference Laboratory in 2012. The result was that a new TSE Regulation (Regulation 56/2013) came into force in February 2013 and now (starting from 1 June 2013 onwards) non-ruminant processed animal proteins can be used in aqua feed in the EU. Re-use of ruminant PAPs for feeding non-ruminant farmed animals remained prohibited and due to safety reasons its re-authorization is not expected in the near future. The previous decision to ban the feeding of most animal proteins to ruminants was upheld, additionally the European Commission (EC) has not authorized so far the use of porcine PAPs in poultry feed or poultry PAPs in pig feed due to the lack of validated diagnostic method to test for non-ruminant material in feed, to avoid any risk of intra-species recycling. However, the EC has suggested that if a diagnostic tests for the detection of non-ruminant material are approved by the EU Reference Laboratory for animal proteins, and the reorganization of European ABP processing industry to deliver species specific sources of PAP, avoiding cross contamination by dedicated transports, processing lines and compound feed plants, is completed, the way to the use of non-ruminant PAPs in the pig and poultry sectors will be clear (Spence et al., 2013). According to dr Martin Alm, who is a technical director of European Fat Processors and Renderers Association (EFPRA), a number of PAP producers in the EU have already embraced the changes necessary to deliver high-quality, species-specific and traceable PAPs, moreover their products placed on the aqua feed market are exceeding regulatory requirements. He claims also that PAP products manufactured in the EU are proven to be safe and of unique nutritional and environmental credentials, and there are no obstacles (political or scientific), to re-authorize them in non-ruminant feed by the end of 2015 (Feedinfo, 2014). According to the Europe's leading feed authorities i.e. Federation of European Aquaculture Producers (FEAP), European Feed Manufacturers' Federation (FEFAC) and EFPRA, the decision to permit PAP for use in aqua feed has had a hugely positive impact on the animal by-product sector and sustainability of fish farming in the EU. They emphasize that utilizing European PAP as feed ingredient reduces the need for imported proteins, such as soya and fishmeal, and increases home –production of protein-rich ingredients, and helps European aquaculture industry grow and remain competitive against the non-EU producers (Feedinfo, 2014).

Types and characteristic of ABPs authorized for animal feeding in the EU

ABPs, according to ABP Regulation, comprise animal bodies or parts of animals, and products obtained from them, which are not intended for human consumption. Types of ABP material include: butcher and slaughterhouse waste, blood, feathers, wool, hides and skins, fallen stock, dead pet and zoo animals, manure, ova, embryos, semen, and catering waste from commercial and household kitchens, and former foodstuffs of animal origin from food manufacturers and retailers. Among these, only a few can be legally fed or included in feedstuffs intended to farm animals in the EU i.e. low risk category 3 ABPs, and when subject to certain conditions, such as sourcing, processing and controlled storage. A processing step, including almost always sterilization, is required prior to use any ABPs in animal feed, with a few exceptions including eligible former food products. According to EFPRA, which is one of Europe's leading authorities on the safe disposal of animal fats and meat industry by-products, around 18 million t emerge annually in the EU from slaughterhouses, plants producing food for human consumption and dairies. These residue materials are subsequently processed into about 4 million t of animal fats and proteins, and processed animal proteins account for about 2.5 million t (http://www.efpra.eu). The volume of FF produced by EU Member States that might be used for feeding purpose is difficult to estimate, but it can be legitimately assumed to be around 8 to 12 million t arising from food industry and retail, without fruits and vegetables removed from the food chain. According to FEFAC, there are about 100 registered food processors in the EU (about 75% of all is located in Old Member States), that annually process and recycle 3 – 3.5 million t of FF to compound feeds (FEFAC, 2012).

The list of ABP materials that can be recycled to livestock (both ruminants and non-ruminants) feed is the following (see also Table 3):

- former foodstuffs (not containing meat, fish or shellfish)
- animal fats and fish oils
- hydrolysed proteins
- collagen and gelatine from non-ruminants
- milk and milk-based products
- eggs and egg products (GOV.UK, 2014a).

ABPs that can be fed only to non-ruminant animals include:

- processed animal proteins (PAPs):
    - fish meal
    - PAPs from pigs and poultry for farmed fish
- blood products and blood meal
- di-calcium and tri-calcium phosphate (GOV.UK, 2014a).

Former foodstuffs (FF) comprise expired products or products no longer intended for food use due to practical or logistical reasons, such as surplus, problems with manufacturing, or other defects, which do not present any health risk for further use as feed (Jensen, 2012). Food products containing any ingredient of animal origin, and no longer fit for people consumption, fall under ABP Regulation (all classified as low risk category 3 material) and this decision cannot be reversed. Only certain FF from premises such as bakers, supermarkets, retail stores, crisp manufacturers and confectioners (although not from kitchens and restaurants based on these premises) can be used for feeding farm animals. However, they still have to be safe and cannot be decomposed, mouldy or contaminated with any toxic chemicals. Additionally, FF cannot contain or have had any contact with raw meat, fish or shellfish. Food items that are mainly recycled for livestock feeding include bakery products (bread, cakes, pastry, biscuits), pasta, chocolate, sweets and similar products, such as breakfast cereals, which may contain rennet or melted fat, milk and milk products, flavourings, eggs, honey, collagen or gelatine of non-ruminant origin (GOV.UK, 2014a). Food retailers, supermarkets or food manufacturers supplying former foodstuffs on feed market have to be registered as feed business operators, and they are obliged to follow the Feed Hygiene Regulation (Regulation 183/2005).

In general, FF retain a significant nutritional value for animal feed purpose, because of their high energy content in the form of sugars, oils and starch. Their use in compound feed allows to replace other raw materials, such as cereals, that are generally used in animal diets for their energy content (Table 4), e.g., a biscuit meal (typical product resulted from processing of former foodstuffs) used in feed formulation for pigs may be nutritionally equivalent to barley or wheat (http://www.effpa.eu).

Animal fats and oils which can be used for animal feed include either fats intended for human consumption or fats that are the product of rendering of category 3 ABPs, including materials fit for human consumption but not intended for it. They can be sourced from both ruminants and non-ruminants, and include among others fish oil, poultry fat, lard (fat from pigs), tallow (fat from cattle and other animals), butterfat and vegetable oil used to fry meat or fish and glycerine from biodiesel site, when it is extracted from 3 ABP material. However, they cannot be contaminated with animal protein, such as tissue, muscle fibre and bone, to avoid the risk of TSE. Additionally, animal fats are categorized by their origin i.e. the animal they come from, resulting in several types bearing specific Combined Nomenclature (CN) codes, such as 1501 00 – pig and poultry fat, 1502 00 – fats of bovine animals, sheep or goats, or 1504 00 - fats and oils from fish or marine mammals, etc. The fatty acid (FA) composition of common fats and oils, together with the ratio between unsaturated and saturated forms (u:s ratio), which are important factors regarding to the gross energy content and digestibility of fats, can differ significantly depending mainly on their origin. For example tallow is low in polyunsaturated FA, and lard is relatively high in C16:0 and C18:1 forms of FA (Doppenberg et al., 2015). Fat digestibility is species dependent (lower for poultry than for pigs), age dependent (lower for young animals) and strongly affected by gut health (Doppenberg et al., 2015). Rendered animal fats may be susceptible to oxidation (become rancid) and rancid fats are unpalatable to animals, and may even be toxic inducing diarrhoea, liver problems and encephalitis. Thus, to prevent this adverse conversion it is often necessary to add an antioxidant to formulated feeds, such as butylated hydroxyanisole, butylated hydroxytoluene or ethoxyquin. Total EU production of animal fats was about 3.2 million t in 2010 and has been relatively stable since 2005. The major streams of animal fat were represented by lard – 62%, tallow – 34% and fish oils – 4%. The largest EU producers of pig fat in 2010 were Germany, Spain and Poland. For tallow, the biggest producer was France, followed by United Kingdom and Germany; whilst Denmark was the largest fish oil producer in the EU (Dekra, 2011). Statistics on the disposal of animal fat in 19 EU Member States during the years 2006-2010 show that the most important use of them was animal feed, followed by oleo-chemical production, energy purpose and biodiesel. However, biodiesel production has grown rapidly during the last years and it is expected to become the most important use of animal fat in the near future in the EU (Dekra, 2011).

Hydrolysed protein, as defined in the ABP Regulation, is a product of animal protein hydrolysis which comprises polypeptides, peptides and amino acids, and mixtures thereof. It can be obtained after hydrolysis of either ruminant or non-ruminant ABP material, and for final product the limit of a molecular weight below 10 000 Dalton applies. Additionally, the production process has to involve the preparation of raw category 3 ABP material by brining, liming and intensive washing, followed by exposure of the material to a highly acidic (≤ 2) or alkaline (≥ 11) pH and heat treatment (140 °C) under pressurized condition (≥ 3 bar) to minimize the risk of contamination. Feed business operators wanting to process ABPs into hydrolysed protein for animal feed need to comply with the requirements of the TSE Regulation and ensure that product being used for farm animal feed does not contain animal tissues, such as bones, feathers and muscle fibres (GOV.UK, 2014a). The commercially available products of animal protein hydrolysis have the form of powder or granules, which are easily soluble in water. They are highly digestible, and particularly high in arginine, proline and glycine, and considered as valuable protein source in farm animal feed, especially for aquaculture. Moreover, due to the rising prices of fish meal, its growing replacement with vegetable protein sources, which are less digestible, attractive and palatable for farm animals, needs a compensation in the form of easily absorbed protein rich in essential amino acids, such as hydrolysed products.

Collagen is defined in Regulation 1069/2009 as protein-based product derived from hides, skins, bones and tendons of animals. As a nutritional supplement, hydrolysed collagen is well resorbed and plays an important role in preventing arthritis or the preliminary stages of osteoporosis, which are common not only in humans but also in animals. Collagen containing products suitable for farm animal feed can be sourced from non-ruminant animals only (GOV.UK, 2014a). Products containing collagen are commercially available in the form of highly water soluble powder or granules. It is commonly used in equine joint supplements.

Gelatine is defined in ABP Regulation as natural, soluble protein, gelling or non-gelling, and obtained by the partial hydrolysis of collagen produced from bones, hides and skins, tendons and sinews of animals. Its use in farm animal feeding is mainly as an ingredient of confectionery and bakery products (GOV.UK, 2014a). Gelatine has hydrophilic properties, makes the feed easy to digest and also protects vitamins enriching feeds from light and oxygen. The TSE-related feed ban prevents the use of products containing ruminant gelatine in all farm animal feed. Feed businesses operators sourcing confectionery or bakery products must ensure that suppliers are sending only material containing non-ruminant gelatine (GOV.UK, 2014a).

Milk and milk products that can be used as farm animal feed include raw or pasteurized milk or milk products, whey from non-heat treated milk, cleaning water used in contact with pasteurized or raw milk, and colostrum. Additionally, some dairy FF such as cheese, yoghurt, butter, cream and ice cream can be destined for livestock feeding. Unprocessed milk and milk products, such as leftover whey, can only be fed to animals directly on a farm level. Whereas, processed milk or milk products can also be used in feeds available for general sale, and they tend to be one of many ingredients in a compound feed products (GOV.UK, 2014c). The processing standards required when milk based feeds are for general sale include mainly different types of sterilization, by applying adequate heat treatment and pH adjustment, giving the example of pasteurization followed by pH reduction to the value lower than 6. Processing plants supplying products with a minimum 80% milk content, and farms use them for feed, have to be officially registered, due to enable rapid control response and traceability in the event of a disease outbreak (GOV.UK, 2014d). Milk and milk products can be used as a source of dietary energy, protein, vitamins and minerals in livestock feeding programmes. The major components of unprocessed milk are water, fat, protein and carbohydrate. Additionally, there are other highly important micronutrients such as vitamins and essential minerals. Milk is a good source of high quality protein, for example cows' milk contains about 3.5% by weight (80% is casein and 20% whey). The principal carbohydrate found in milk is a disaccharide lactose, and cows' milk contains about 4.5% by weight. The bacterial conversion of lactose into lactic acid is the basis for several dairy products. Milk fat is composed mainly of triglycerides – saturated and monounsaturated fatty acids attached to a molecule of glycerol. Whole milk contains around 3.5% of fat by weight. The fat droplet is a carrier for most of the cholesterol and vitamin A present in milk. It is also a good source of B vitamins, especially B_2, B_1, B_{12}, and minerals such as calcium, phosphorus, iodine and potassium. Several completed reviews concerning the feeding of farm animals with dairy by-products, such as liquid and dry whey, are currently available (Schingoethe et al., 1973; Anderson, 1975; Landblom and Nelson, 1980). Thus, dairy by-products were found to be a good source of supplemental protein, especially skim milk and buttermilk, and carbohydrate, minerals and B vitamins, especially whey and buttermilk, for most food producing animals.

Eggs and egg products, which are classified as category 3 ABP material, have to be processed before use in farm animal feed in either an approved establishment or a food factory. This requirement also applies to egg shells when they are used as a grit or highly available source of calcium for poultry. A hatchery waste, comprising dead-in-shell chicks, belongs to the category 2 ABPs, thus it is forbidden for use in the production of feed for farmed animals. At a food factory they should be treated in accordance with Food Hygiene Regulation

(Regulation 853/2004), which sets out the hygiene and safety requirements for the marketing of egg and egg products for food businesses (GOV.UK, 2014a). The avian egg consists of about 10% shell, 58% albumen and 32% yolk, and an average weight of chicken egg is about 60 g. The nutritive content of an average chicken egg includes 6.3 g protein, comprising all essential amino acids, 0.4 g carbohydrates, 5.0 g fats and 0.2 g cholesterol. Additionally, eggs are an important source of vitamins, mainly A, B_2, B_{12} and D, and minerals, especially phosphorus, calcium and iron, present as highly bioavailable organic chelates. Thus, the egg is said to be one of the most complete foods available. Nevertheless, some of *in vivo* trials with weanling pigs where inedible egg product (mixture of whole eggs and egg albumen containing 55.2% protein and 28.6% fats) was used as protein and fat source in diets showed a depressing effect on growth performance in comparison to soyabean meal and oil (Zimmerman, 2000). However, the effect was explained by diet differences related to the protein sources and possible destruction or complexing of some essential amino acids before or during the process of drying the egg product.

ABP materials characterized below can only be used in non-ruminant feed.

Processed animal proteins (PAPs) are slaughter by-products obtained from healthy animals, classified as 3 ABPs, which have been processed in accordance with required and approved manners to render them suitable for use as feed material. There are different types of PAP, such as blood meal, meat meal, bone meal, horn meal, feather meal and fish meal. Mammalian proteins, which are authorized for feed but not classified as PAP include milk and milk products, eggs and egg products, collagen and gelatine. Currently, only restricted processed animal proteins can be legally fed to livestock in the EU, subject to non-ruminant animals only and preventing intra species recycling. Pork and poultry PAP may be used in aquaculture sector (since 1 June 2013), and fish meal to feed pigs, poultry, horses and farmed fish. It is forbidden to feed ruminants with any form of PAP in the EU, with the exception of fish meal that is authorized as milk replacer for weaning animals. In general, PAP has a significant nutritional value for animal feed purpose, particularly because of high protein content (Table 5). However, the composition of nutrients depends on the source of ABPs used, and also on the processing technology involved. Processed animal proteins are considered as complete source of protein, they contain all nine essential amino acids in relatively balanced quantities. They are also highly and easily absorbed by animals. One of such essential amino acid is lysine, which reduced level in diet may limit the growth of livestock due to preventing synthesis of protein. PAP is very rich in bioavailable lysine (Wang and Parsons, 1998). In contrast, vegetable proteins often comprise of an essential amino acids, however they tend to have a low content of those with branch chains. Processed animal protein deliver also easily digestible energy in the form of fat, which can amount to 16% of dry matter. Additionally, PAPs contribute to the nutritional needs for calcium, phosphorus and vitamin B_{12}. According to farm animal researchers (Georgievskii et al., 1981; Better Crops, 1999) about 85% of phosphorus in animals is deposited in non-edible parts, thus PAPs contain high volumes of it (Alm, 2012a). Contrary to the plant sources, phosphorus occurs in processed animal proteins in a highly digestible form. For example, poultry can digest 62% of this mineral contained with meat and bone meal but only 42% in soya meal and 33% in rapeseed meal (Alm, 2012b). Additionally, PAPs are able to contribute to the nutritional needs of food producing animals for vitamin B_{12} (Alm, 2012b).

Fish meal is a type of PAP obtained after cooking, press drying and squeezing fresh raw fish or trimmings from food fish. Product is commercially available in the form of coarsely ground brown powder. Fish meal contains typically 60 to 72% protein, 10 to 20% ash, 5 to 12% fat and has a high content of the human health-promoting fatty acids, including eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids (The Fish Site, 2012). It is used primarily in feed for farm-raised fish, pigs and poultry. In 2008, the aquaculture sector consumed 58% of the global production, the pig sector – 32%, and the poultry sector – 9%, that gives 99% of the total production (The Fish Site, 2012). The global fish meal output has remained at 6 to 7 million t annually for the last 20 years, while world trade has averaged around 3 to 4 million t (The Fish Site, 2012). The largest producers are Peru, China, Chile and the Nordic countries (Norway, Denmark and Iceland), making up approximately 80% of global production. In turn, the largest consumer of fish meal is China, which uses between 1.6 and 2.0 million t annually, and from European countries a Norway with consumption level around 0.35 million t per annum (The Fish Site, 2012). According to some marine biologists, the growing use of fish meal in animal feed presents problems from an environmental perspective, because most fish meal is not produced as a by-product of catching fish for human consumption, but millions of tonnes of fish, including juveniles, are harvested each year for processing into animal feed (http://www.animalwelfareapproved.org/standards/animal-byproducts).

Blood from non-ruminant animals, classified as low risk category 3 ABP, can be used to make either **blood meal** or **blood products** for feed purpose. The difference between them is subtle and relates mainly to the ABP from which the starting material can be sourced. Blood products can be derived from blood resulting from slaughterhouses equipped with a separation system that removes blood from animals that fail post-mortem examinations, and include dried/frozen/liquid plasma, dried whole blood, dried/frozen/liquid red cells or fractions thereof. Blood meal can be sourced from ABP material when there is no separation system in place, and it is obtained by heat treatment of blood of slaughtered warm-blooded animals. Blood products can be used for feeding all non-ruminants, whereas blood meal only for farmed fish and shellfish (GOV.UK, 2014a). Blood processors supplying blood meal or blood products have to be authorized under the TSE Regulation and label their products appropriately. To reduce the risk to very low level of possible relevant hazards, mainly major notifiable diseases, to enter the feed chain, the plants rendering blood should use sufficient temperatures for a sufficient time to inactivate viruses, bacteria and other agents. A common processing method for blood products for animal feed use is spray drying, where an inlet temperature is of 160-300 °C and minimum contact time is between 10 to 30 s; and an outlet temperature of 70-90 °C (DARDNI, 2014). Blood meal contains mostly protein - 90-95% of dry matter and small amounts of fat - less than 1% and ash - less than 5%, though it may include other materials and thus be richer in ash. Unlike other animal protein sources, it has a poor amino acid balance. Its lysine content is relatively high and amounts to 7-10% of dry matter, but the content of isoleucine is very low and reaches up to 1% (Feedipedia, 2015). Therefore blood meal is a good supplementary feed to use with plant-derived feed ingredients that are low in lysine. It is also rich in iron which amounts to 1500 $mg \cdot kg^{-1}$. The availability of the protein fraction of blood meal is very high, however if overcooked it can be unpalatable, and so care needs to be taken not to add more than 5-6% blood meal to a ration, especially if high feed consumption and performance are desired. Often an adaptation period is required to habituate the animals to eat blood meal (Feedipedia, 2015).

Di-calcium and **tri-calcium phosphate** are ionic salts, commonly used in mineral form as feed supplements for livestock, poultry and pets. Di- and tri-calcium phosphate can be also sourced from non-ruminant ABPs. Additionally, because of the increasing cost of extracting inorganic feed phosphates, world consumption of organic origin supplements is growing in recent years. Both salts can arise as a co-product during the gelatine production process. When they are derived from defatted bones, according to the legislation, they have to come from bones of animals fit for human consumption following ante- and post-mortem inspections. For any businesses wanting to manufacture di-calcium and tri-calcium phosphate from ABPs for feed purpose the specific requirements, which apply to the sourcing and processing of animal material, can be found in the ABP Regulation (GOV.UK, 2014a).

In turn, there are a number of other category 3 animal by-products which are forbidden by EU legislation for use as farm animal feed, and these include:

- catering waste
- kitchen scraps
- raw meat, fish and shellfish or any ABPs containing them
- fully or partially cooked meat, fish and shellfish or any ABPs containing them
- unprocessed products of animal origin (including egg and milk products)
- former food products that are decomposing, mouldy or toxic (GOV.UK, 2014a).

Potential animal and human health impacts associated with feeding farm animals with ABP material

Because of current feeding practices, the number of different etiologic agents have been detected in either animal feeds or resulting animal food products. Some of them may be associated with the incorporation of rendered animal products into animal diet, and these include bacterial pathogens and their toxins, viruses, prions and dioxins (Crump et al., 2002; Eljarrat et al., 2002; Moreno-López, 2002). Raw ABPs contain large number of microorganisms, including pathogenic bacteria and viruses (Hamilton et al., 2006). Unless properly processed, these ‘unstable’ materials provide an excellent environment for disease agents to grow and potentially threaten animal and human health, and the environment. Additionally, if allowed to accumulate and decompose immoderately, ABPs would become a substantial biohazard, promoting disease, attracting and harbouring rodents, insects, scavengers and predatory animals into densely populated areas (Hamilton et al., 2006). Processed animal residues have been used for years by feed industry as a source of nutrients, vitamins and minerals in commercial concentrates.

One of the best known feed ingredient sourced from animals is a meat and bone meal (MBM), which had been extracted from dead stock and slaughter by-products, and widely incorporated into livestock diets in Europe in the second half of the 20th century. MBM had become a strategic and economical source of both proteins and phosphorus for farm animals. However, its unregulated and improper use resulted in a strong food crisis in Europe at the beginning of the 1990's, which seriously affected both consumers and livestock producers. The bovine spongiform encephalopathy (BSE, mad cow disease) outbreak occurred in Western Europe - mainly in the United Kingdom, where about 180,000 cattle were found to be infected, which further led to the slaughter of more than 4 million animals during the eradication programme. Meat and offal from hundreds of thousands of infected animals had entered the human food chain, and by 2009 had resulted in about 200 human deaths worldwide, because of new variant of Creutzfeldt–Jacob disease (vCJD) (Cleeland, 2009). Prion proteins were identified as the infectious agent, and the epizoonosis was caused by the feeding of cattle with inadequately processed MBM, which caused the prions to spread (Prusiner, 1997).

Furthermore, feed scientists have linked some of an outbreaks of notifiable animal diseases to the feeding of farm animals with feeds containing improperly processed and sterilized food waste and slaughterhouse by-products. The examples include cases of swine vesicular disease (SVD), classical swine fever (CSF), foot-and-mouth disease (FMD) and avian influenza, correlated with feeding farm animals with garbage and meat products in which infectious agents (viruses) were detected (EUFIC, 2006). In general, pathogenic viruses can be highly variable, which result in a very wide range of symptoms, from relatively mild disease to highly contagious, rapidly fatal form of the disease, such as an avian influenza, caused by different subtypes or strains of the same virus. Additionally, they can spread rapidly amongst farm animals, and in case of outbreak of notifiable disease farmers can lose huge amounts of money due to wide-scale destruction of animals and/or the fall in meat and milk prices. An epizootic sometimes may have very strong economic impact on both the agriculture and food industry, with the example of an outbreak of FMD in 2001 in the UK (FootAndMouthDiseaseInfo, 2015). Animal viruses pose much greater threat to the agriculture than to human health, nevertheless in some cases people can be affected by different virus strains through close contact with infected animals or after eating raw food products (EUFIC, 2006). Among these are FMD and avian influenza virus, the results of infection for both viruses are considerably different, i.e. in the first case the disease in humans is relatively benign, whilst the latter one can be lethal to humans and has been causing global concern as a potential pandemic threat, with confirmed about 440 dead people from the influenza A virus subtype H5N1 according to WHO (WHO, 2015).

There is also the risk of introduction and transmission of pathogenic bacteria, such as *Salmonella*, *E. coli*, *Campylobacter*, *Listeria*, *Clostridium botulinum* or parasitic protozoan, including *Toxoplasma*, along the food chain by feeding the animals with contaminated recycled material (Orris, 1997). Some of them are ubiquitous in the environment, including gastrointestinal tract of animals and humans, which makes eradication impossible. In animals, bacterial disease may manifest as one or more syndromes, such as septicaemia, acute enteritis and chronic enteritis, but livestock can also be carriers without showing clinical signs of infection (EUFIC, 2006; EFSA, 2011). For instance, the most common *Salmonella* serotypes involved in human foodborne illness are *S. enteritidis* and *S. typhimurium*, but these often cause only mild, if any, disease in livestock (EUFIC, 2006). Eating meat contaminated with pathogens can cause food poisoning, with symptoms ranging from mild (stomach cramps and diarrhoea) to life-threatening (organ failure and death). According to EFSA, about 5,200 food-borne outbreaks and over 320,000 human cases of food-borne zoonotic diseases are reported each year in the EU, however the real number is believed to be much higher (EFSA, 2011). The most commonly reported zoonosis in Europe is campylobacteriosis, followed by salmonellosis and yersiniosis (EFSA, 2015). Most food-borne outbreaks in the EU in 2013 were caused by *Salmonella*, followed by viruses, bacterial toxins and *Campylobacter*. The most important food carriers in the strong-evidence outbreaks in the same year were eggs and egg products, followed by mixed food, fish and fish products, and poultry meat (EFSA, 2015). Although, potential risks associated with foodborne pathogens are minimized through stringent animal health and food quality control measures, contamination of carcasses, milk and eggs cannot be completely prevented.

Other unintentional contaminants of animal feed, which may be attributed to the use of ABPs include dioxins, such as polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Their presence in the environment is strongly linked to human activities, including the incineration of plastics and wide-scale use of chlorinated chemicals in the industry. Dioxins are highly lipophilic compounds, and when contaminated plant-based feeds are fed to food-production animals they bioaccumulate in fat tissues, making the use of rendered animal fats and oils a significance source of exposure to dioxins among farm animals (Sapkota et al., 2007). Subsequently, animal-based food products, including fish and dairy products, are the largest dietary contributors to PCDD and PCDF exposures in the human populations in industrialized countries. Chronic exposures to these compounds can result in adverse health effects ranging from cancers to impairments in the immune system, endocrine system and reproductive organs (WHO, 2014). The most important example of dioxin-contaminated animal feed occurred in Belgium in 1999, where fat-melting company accidentally incorporated mineral oil contaminated with 1 g of dioxins into a mixture of animal fats intended for feed, which finally resulted in elevated levels of these chemicals in animal food products, such as eggs, poultry and pork (van Larebeke et al., 2001). There are studies describing higher levels of PCDDs and PCDFs in eggs from hens raised on soils contaminated with these compounds (Schoeters and Hoogenboom, 2006). Elevated levels of dioxin were also detected in farmed salmon versus wild-caught salmon, due to contaminated commercial feed (Easton et al., 2002). However, available data shows that the background exposure to PCDDs and PCDFs in Europe has decreased over the last 15 years, and the EU policy on dioxins aims at further reducing the levels of these contaminants in the environment, feed and foodstuffs in order to secure a higher level of public health protection (Dioxin Report, 1999).

The human and animal health risks linked to feeding animals with ABPs are very well documented, and due to safety reasons only a few types of ABPs can be destined for livestock feeding, and if specific conditions for storage, processing and transport are met. The EU feed and food safety strategy provides extensive legislation and outlines the responsibilities of ABP suppliers and processors, compound feed industry and livestock producers in ensuring the safety of animal-based food supply. Diseased animals cannot enter the food chain system at any stage. For example, milk from cows with an udder infection cannot be delivered to the dairy plant or administered to farm animals. Animals arriving at the slaughterhouse are first inspected for signs of clinical illness before they enter the premises. Needless to say, any deviation from normality, when carrying inspection procedures, leads to rejection of the carcass, offal and by-products for further feed and food use (EUFIC, 2006). To ensure the transparency and traceability of ABP materials, the ABP renderers and former foodstuff processors running in the EU have to be officially registered. According to EFPRA, processing plants in Europe rely on modern quality management systems (GMP, HACCP and Quality Assurance Standards – ISO 9000 and ES 29000) to ensure the quality and safety of the products they produce against cross contamination by meat and other products of animal origin not intended for animal feed. Additionally, all along the food chain system in the EU member states, a various procedures, control mechanisms and alert tools (RASFF) are implemented to assure safe quality food and minimize the risks of contamination.

Conclusions

The newest European Union food and feed policy provides extensive legislation to safe disposal and use of animal by-products in farm animal feeding. It has been emphasized that food and feed safety can only be ensured by shared responsibility of suppliers and processors of ABP materials, and compound feed industry and livestock producers. The last changes in the legislation refer to the authorization of non-ruminant processed animal proteins in aqua feed. The approval of PAPs in the pig and poultry sectors is possible only when validated diagnostic methods to test species specific product in feed are established.

According to the newest EU resource efficiency expectations the feed use of ABPs and former foodstuffs is a way of optimization towards achievement of maximum nutritional potential. Considering Europe's deficit of protein-rich feed ingredients, animal by-products may serve as an economical source of protein, and other important nutrients and energy. Furthermore, a number of ABP materials are nowadays described for nutritional value and possible application in farm animal diets.

The use of permitted rendered animal products in livestock diet can be carried out but only under constant supervision, due to possible presence of pathogenic microorganisms and chemicals, and their strong adverse effects on human an animal health and the environment. It should be stressed that stringent EU regulations and implemented control systems (GMP, HACCP) and rapid alert tools (RASFF) considerably minimize the risk of supplying contaminated feed material.

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Table 1. Edible and inedible portions of slaughtered animals, % of live weight (Alm, 2012a)

Slaughtered animal	Edible = human consumption, %	Inedible = by-product, %
Chicken	68	32
Pig	62	38
Cattle	54	46
Sheep/Goat	52	48

Table 2. Management of three categories of animal by-products (ABPs), according to Regulation 1069/2009

ABP category	Disposal and use (according to EU legislation)
Category 1	incineration in an approved plant or bury in an authorized landfill
Category 2	incineration and/or rendering, or at an authorized landfill site, or recycling for uses other than feed after appropriate treatment, such as chemical industry, organic fertilizers, biogas production
Category 3	disposed in a various ways, including incineration and rendering, bury in authorized landfill, composting, anaerobic digestion, feeding to farm and pet animals, or other approved manner

Table 3. Summary on authorization of different animal by-products (ABPs) in farm animal feeding in the EU

ABP material	Ruminants (cattle, sheep and goats)	Non-ruminants (pigs and poultry)	Aquaculture (fish and shellfish)
Former foodstuffs	permitted – under requirements of Feed Regulation	permitted – under requirements of Feed Regulation	permitted – under requirements of Feed Regulation
Fats from ruminants and non-ruminants and fish oils	permitted	permitted	permitted
Hydrolysed protein from ruminants and non-ruminants	permitted	permitted	permitted
Collagen and gelatine from non-ruminants	permitted	permitted	permitted
Milk products	permitted	permitted	permitted
Egg products	permitted	permitted	permitted
Fish meal	banned (with the exception of use as milk replacer for young animals)	permitted	permitted
PAPs from non-ruminants	banned – under TSE Regulation	banned – under TSE Regulation	permitted
Blood products and blood meal from non-ruminants	banned – under TSE Regulation	permitted (only blood products)	permitted
Di- and tri-calcium phosphate from non-ruminants	banned – under TSE Regulation	permitted	permitted
Catering and kitchen waste	banned – under ABP Regulation	banned – under ABP Regulation	banned – under ABP Regulation
PAPs from ruminants	banned – under TSE Regulation	banned – under TSE Regulation	banned – under TSE Regulation

PAPs - processed animal proteins, TSE - transmissible spongiform encephalopathies

Table 4. The nutritive value of processed former foods (http://www.effpa.eu)

Indices	Former foodstuffs – typical pig feed formulation	Barley	Wheat
Dry matter (DM), % feed	88.0	88.0	88.0
% DM			
crude protein	10.0	11.0	12.4
lysine	0.38	0.38	0.34
crude fat	14.5	2.8	2.1
crude fibre	2.2	5.5	2.7
starch	41.0	51.6	59.2
sugar	14.0	2.2	2.4
Metabolizable energy pig, MJ · kg^{-1}	16.75	12.95	14.43

Table 5. Nutritive composition (% dry matter) of different non-ruminant processed animal proteins (PAPs; Alm, 2012a, with modifications)

Indices, % dry matter	Blood meal	Feather meal	Poultry PAP	Pork PAP	Fish meal
Protein	90-95	80-85	60-68	45-65	60-72
Fat	1	7-11	12-16	12-16	5-12
Phosphorus	0.2-1	0.5	2-3	3-7	2-3
Ash	2-3	4-10	10-20	22-35	10-20
Water	4-7	6-8	4-7	5	9

Figure 1. General scheme of rendering production flow chart for animal by-product (ABP) material (Alm, 2012a). PAP - processed animal protein