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MINOR REVIEW

The role of rendering in relation to the bovine spongiform encephalopathy epidemic, the development of EU animal by-product legislation and the reintroduction of rendered products into animal feeds

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Abstract

The bovine spongiform encephalopathy (BSE) epidemic in 1986 highlighted the importance of the rendering industry as a key component of the food supply chain. Prior to 1986 the rendering industry was poorly understood. However, following the emergence of BSE research was commissioned to characterise rendering systems and investigate their ability to inactivate transmissible spongiform encephalopathy (TSE) agents. Six rendering systems were found to be operational in Europe but their key process parameters, such as particle size, process temperature and transit time, were poorly characterised. This review describes how these key process parameters were determined and used to inform protocols for the subsequent TSE inactivation trials which subsequently shaped both EU legislation and the development of techniques used to validate rendering systems. It also describes how EU legislation banning the use of animal-derived proteins in animal feeds ('feed ban') effectively eliminated the market for meat and bone meal (MBM) and how the rendering industry sought to 'add value' to rendered products by conducting research to support the development of new markets for rendered products. The nutritional, environmental and economic characteristics of modern processed animal proteins (PAPs) mean that they represent valuable ingredients for use in animal feeds. Recent research has paved the way for legislative changes allowing the safe reintroduction of non-ruminant PAP into aqua-feeds and may soon facilitate their reintroduction into pig and poultry feeds. However, resistance from key stakeholders in the food chain remains a significant challenge that must be overcome before their full potential can be realised. Further research is required to characterise modern PAPS and to ensure their appropriate, safe and acceptable inclusion in animal feeds.

KEYWORDS
animal by-products, EU legislation, processed animal protein, rendering

1 | INTRODUCTION

Following the bovine spongiform encephalopathy (BSE) epidemic in 1986 the use of meat and bone meal (MBM) was banned in the diet of animals kept for food production (EC No. 999/2001) (Regulation (EC), 2001). However, with increasing demand for animal products, and sustainable intensification of production systems, the nutritional, environmental and economic characteristics of modern processed animal proteins (PAP) mean that they represent valuable ingredients and the EU is currently considering relaxing the legislation to allow their reintroduction into animal feeds. BSE was arguably one of the most significant animal diseases in the 20th century, with over 180,000 cattle being infected, 4.4 million slaughtered up to the end of 2000 and an estimated cost of £5 billion (Brown et al., 2001). The emergence of BSE in 1986 and its subsequent evolution as an epidemic brought animal by-products (ABP) and the rendering industry to the attention of the public for the first time and emphasised their importance in the food supply chain. Before this time, the rendering industry was poorly understood, and it was generally assumed that the BSE epidemic was caused that a relaxation in rendering standards. This review will evaluate the role of the rendering industry in the BSE epidemic, the development of current EU legislation concerning ABP and the recent debate about the reintroduction of PAPs into animal feeds. It will also describe how the rendering industry has evolved in response to the BSE epidemic such that it can continue to operate and provide both a valuable service and products to the livestock and meat industries.

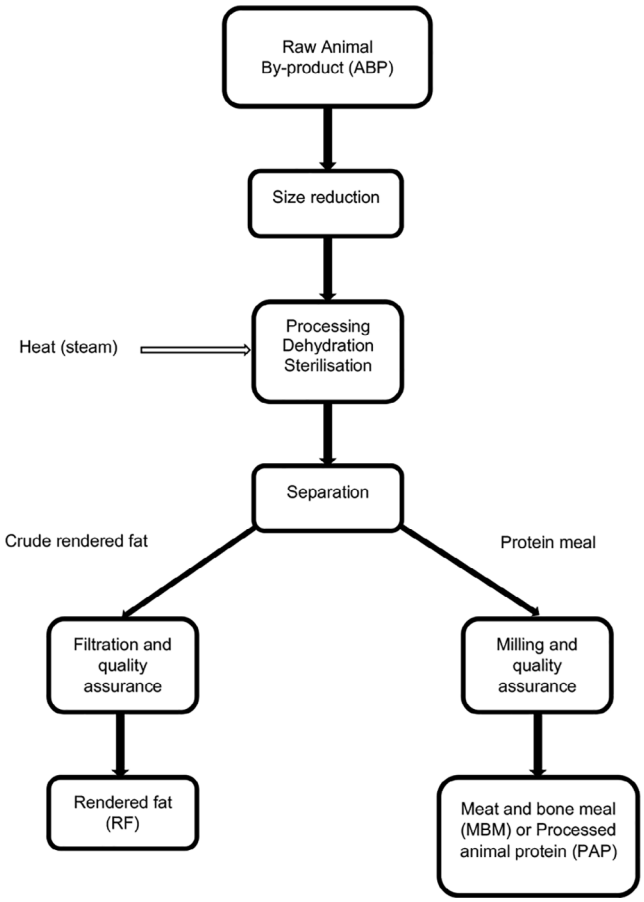

FIGURE 1 Schematic diagram of the rendering process

2 | THE RENDERING INDUSTRY AND BSE

2.1 | Rendering

Rendering is the process of separating (rendering apart) the fat and protein-rich material contained in animal tissues when they are heated to a temperature where the cellular structure is degraded and the fats are released (Woodgate & Van der Veen, 2004). Thereafter, the liquid fat is separated from the protein-rich solid fraction. Although the definition of 'rendering' could equally be applied to the cooking of meat, it is uniquely applied to the heat processing of ABP. In Europe, ABP are defined as whole animals (e.g., fallen stock) or parts of animals raised for human food production that humans choose not to eat (Regulation [EC] No. 1774/2002) (Regulation (EC), 2002b). The key stages in the rendering process are presented in Figure 1. Rendering produces two main products: (1) rendered fat (RF, liquid at >50°C) and (2) a protein-rich solid material termed either MBM (pre-2002) or MBM from Category 1 and 2 material and PAP from Category 3 material (PAP, post-2002). Prior to BSE the RF (tallow) was traditionally used in the manufacture of candles and soaps and was used in the oleo-chemical industry, whereas the protein meal was used as a protein supplement in animal feeds. The rendering industry essentially provides a service to the livestock and meat industries, but in commercial terms, the revenue from selling rendered products must cover the costs associated with ABP processing. Profit margins are effectively maintained by either paying for, or charging for ABP, depending on the value of the rendered products produced. Early development of the rendering industry has been described by Burnham (1978) and for many years it was termed the 'invisible industry' because it operated outside the glare of publicity and legislative controls were limited. If the MBM was 'cooked' (i.e., dry to the feel of the operator) the process was thought to be working well. The legislative controls that did exist centred on the control of Salmonella in MBM as specified in the Disease of Animals (Protein Processing) Order 1981 (Order, 1981).

Between 1970 and 1980 significant changes occurred in the rendering industry. The oil crisis in the mid-1970s resulted in a fivefold increase in the cost of crude oil. With increasing fuel costs the rendering industry became acutely aware of the costs associated with producing process heat (steam) and were forced to consider more energy efficient processes to evaporate the same amount of water using significantly less energy (Kudra & Mujumdar, 2001). Significant investment occurred in a new rendering system designed and built in the United States. Termed the 'Anderson Carver-Greenfield' system, it was designed to minimise fuel use and reduce processing costs. The system was purchased by the main UK rendering company and three plants were quickly established in the UK. By 1982 these plants were processing approximately 30% of UK ABP. The key features of the new system were the incorporation of a two-stage vacuum

TABLE 1 Chemical composition of meat and bone meal (MBM, pre-2002), and processed animal proteins (PAPs, post-2002)

	Pre-2002	Post-2002		
Chemical composition (g kg^{-1} DM)	MBM[a,b]	Poultry PAP[c]	Porcine PAP[d]	Porcine PAP[d]
DM (g kg^{-1})	935	947	970	964–978
Crude protein	529	564	547	416–616
Ether extract	175	107	107	96–118
Ash	250	256	302	183–437
Calcium	57		103	52–160
Phosphorus	28		52	30–77
Amino acids (g kg^{-1} DM)				
Threonine	15.9	22.4	16.9	11.4–20.7
Cysteine	6.2	5.6	3.3	1.5–5.3
Valine	20.1	24.9		
Methionine	7.1	14.3	7.7	4.9–9.3
Isoleucine	13.3	21.6		
Leucine	30.8	38.0		
Tyrosine	10.2	16.9		
Phenylalanine	17.0	22.9		
Lysine	25.7	37.2	28.1	19.7–32.5
Histidine	8.9	14.7		
Arginine	36.2	40.7		
Rumen degradability[e] (outflow rate 0.08)	0.41	Not determined		

[a]Ministry of Agriculture Fisheries and Food (MAFF) (1986).
[b]Wang & Parsons (1998).
[c]Liland et al. (2015).
[d]Van Krimpen et al. (2010).
[e]Agricultural Research Council (ARC) (1984).

evaporation step, with high throughput and reduced temperature because of the vacuum reducing the boiling point of the water. The system used 0.8 kg steam kg^{-1} water evaporated compared to the next most common system which required 1.35 kg steam kg^{-1} water evaporated (Berge, 1986), with a resultant reduction in processing costs of approximately 40%. However, the internal process dynamics of the system remained poorly understood, although the fact that the process temperature was lower than other systems was thought to increase the digestibility and economic value of the MBM as an animal feed (Wang & Parsons, 1998). The process was approved by the Ministry of Agriculture, Fisheries and Food (MAFF) to operate in accordance with the Disease of Animals (Protein Processing) Order 1981 (Order, 1981) and raised no concerns.

2.2 | Meat and bone meal

In the early 1980s the market for rendered products (MBM and RF) was relatively mature. MBM had only one application as an ingredient in animal feeds, where it was widely used in the diets of most farm animals. Its key attribute was its high-protein content and relatively good amino acid balance (Table 1), particularly for pigs and poultry (Crawshaw, 1995). For ruminants, the protein had a low rumen degradability which was important to increase undegradable protein supply (UDP) and satisfy the requirement of high-producing animals. In the UK, the use of high UDP feedstuffs was particularly relevant as dairy farmers were trying to increase milk yields prior to the imposition of milk quotas. In the mid-1980s, MBM was included in ruminant rations at up to 70 g kg^{-1} DM (BSE Inquiry, 2000).

2.3 | Emergence of BSE

In November 1986, BSE was identified in the UK cattle herd for the first time (Wells et al., 1987). BSE is a fatal disease predominately of cattle over 5 years of age that belongs to a group of diseases termed transmissible spongiform encephalopathies (TSEs) that include scrapie in sheep and goats and Creutzfeldt–Jakob disease (CJD) in humans. The disease is caused by the mutation of a protein complex called a prion, producing an accumulation of insoluble glycoproteins and lesions in the brain of infected animals. Disease progression is slow, with the incubation period being up to 5 years and oral ingestion being the most infectious method of natural transmission. Lesions

within the brain progressively affect the host animal's behaviour and mental state causing changes in gait and posture. As the senses become hypersensitive, the host becomes nervous, aggressive and frequently presses their head against objects, eventually leading to recumbency, coma and death (Kimberlin, 1993). At the time little was known about TSE inactivation. However, it was thought that the BSE agent was likely to be difficult to destroy by atmospheric heating alone and that only hyperbaric pressure would be effective (Taylor, 1990).

3 | CHARACTERISATION OF RENDERING PROCESSES

3.1 | Preliminary investigations

Immediately following the emergence of BSE, MAFF commissioned an epidemiological study which concluded that a feed borne vector was implicated in the aetiology of the disease (Wilesmith et al., 1988). A subsequent survey of the animal feed industry then confirmed that MBM was the only common feed factor that could explain the epidemic at this stage (BSE Inquiry, 2000). Thereafter, the spotlight was clearly focussed on MBM and the rendering industry. Unfortunately, owing to its unstructured nature very little information was available. In response, MAFF commissioned a survey of the rendering industry, the objectives of which were to characterise rendering systems, particularly the time and extent of heat treatment during the rendering process (BSE Inquiry, 2000). The results highlighted that there were a wide range of systems in operation but that their internal process dynamics were poorly understood.

In order to better characterise rendering processes, MAFF convened a working group consisting of MAFF, the Institute of Animal Health Neuropathogenesis Unit (NPU), Edinburgh and representatives of the rendering industry in May 1990. The terms of reference of this working group were to formulate a joint research programme to investigate the ability of rendering systems to inactivate TSE agents (BSE Inquiry, 2000). This was quickly subsumed by the Scientific Veterinary Committee of the European Union (SVC), which advised the European Commission on protecting animal health and through that human health in all member states (R. Bradley, 2017, personal communication). The priority of the SVC TSE Working Group was to survey both the United Kingdom Renderers Association (UKRA) and the European Renderers Association (EURA) to characterise rendering systems. The survey results revealed that rendering systems could be characterised by (1) system (batch or continuous), (2) ABP treatment (as-received, added-fat, fat-removed) and (3) pressure treatment (atmospheric, vacuum or hyperbaric). In total, there were 18 potential combinations. However, within Europe only six were operational (Table 2). These consisted of two batch systems and four continuous systems as follows.

3.2 | Rendering systems

3.2.1 | Batch/as-received/atmospheric

This traditional system involved mincing the ABP to approximately 50 mm. The minced ABP was then loaded into a batch cooker with a capacity of 1–10 t via a top hatch/vent. A central paddle then mixed the ABP with heat being applied indirectly via the jacket of the cooker as high-pressure steam. Water was removed as steam through the top vent until the ABP was dry. Subsequently, the processed material was discharged into a trough, prior to pressing and cooling to produce MBM, and a RF product.

3.2.2 | Batch/as-received/hyperbaric

This traditional system was similar to the batch/as-received/atmospheric system described above. However, steam pressure was applied by closing the top hatch/vent after air in the cooker was displaced. The cooker pressure (typically 5–6 bars) was controlled by adjusting the steam pressure in the cooker jacket for a defined period. Following this period, the top hatch/vent was opened to allow the water to evaporate as steam until the ABP was dry.

3.2.3 | Continuous/added-fat/vacuum

As stated previously, the 'Anderson Carver-Greenfield system' (Figure 2) was a relatively new system, which by 1985 was used to process approximately 30% of all UK ABP. The process involved mincing

TABLE 2 Characterisation of rendering systems used in the European Union prior to the bovine spongiform encephalopathy (BSE) epidemic in 1986

	Key process parameters		
Rendering system[a]	System	ABP treatment	Pressure treatment
Batch atmospheric	Batch	As received	Atmospheric
Batch hyperbaric	Batch	As received	Hyperbaric
Anderson Carver-Greenfield	Continuous	Added fat	Vacuum
Stord-Bartz	Continuous	As received	Atmospheric
Equocooker	Continuous	Added fat	Atmospheric
Wet rendering	Continuous	Fat removed	Atmospheric

Abbreviation: ABP, animal by-products.

[a]The rendering industry characterised rendering system by their trade names.

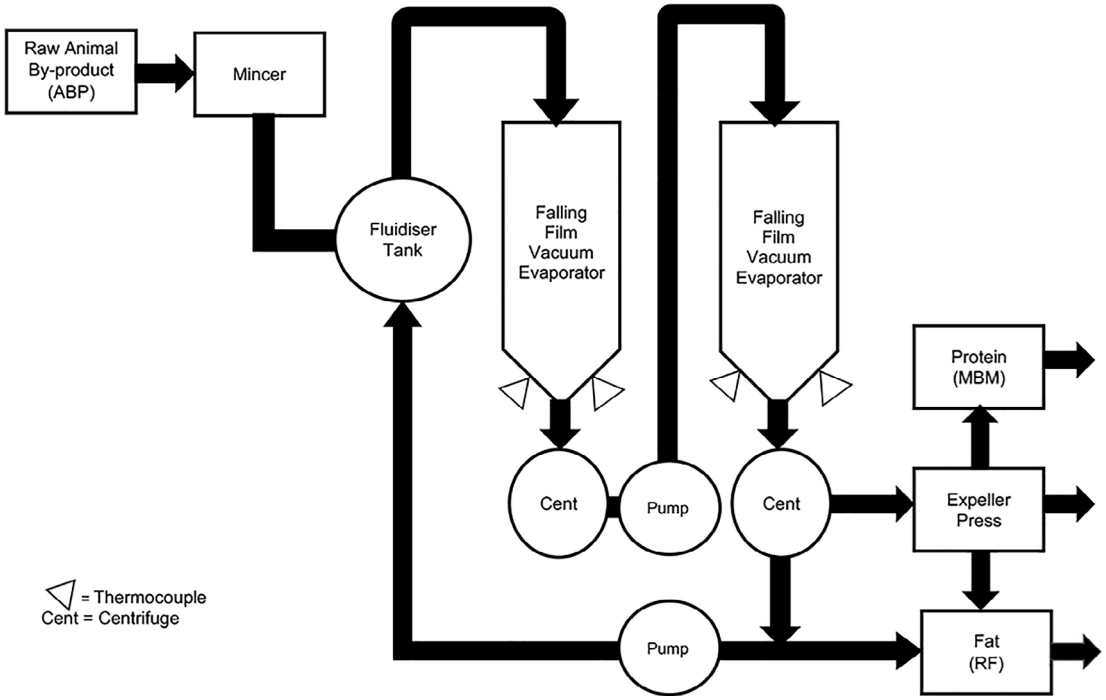

FIGURE 2 Example of a simplified process flow diagram for the continuous/added-fat/vacuum rendering system

the ABP to reduce the particle size to <10 mm. The minced ABP was then mixed with RF in a 1:5 ratio. The RF acted as a carrier for the ABP and medium to maximise the rate of evaporation. The two-stage falling film evaporators facilitated evaporation of water at lower temperatures (first stage 120°C; second stage 105°C) than would occur at normal atmospheric pressure. Subsequently, the RF was then separated by centrifugation with the solid material being pressed and cooled and milled to produce MBM. The rendered fat was then recycled with the system with the excess being filtered to produce a RF product.

3.2.4 | Continuous/as-received/atmospheric

The 'Stord Bartz system' involved mincing the ABP to <30 mm. The minced ABP was then introduced into a continuous disc type drier with the material being moved through the drier by a series of rotating paddles. At discharge, the material was pressed, cooled and milled to produce MBM and RF.

3.2.5 | Continuous/added-fat/atmospheric

The 'Equocooker system' involved mincing the ABP to <30 mm. The minced ABP was then introduced into a cylindrical vessel containing RF heated to 100–125°C (0.60 volume), with the material being moved through the process by a series of rotating paddles. At discharge, the solid material was separated by filtration, cooled and milled to produce MBM. The RF was then recycled within the system, with the excess being filtered to produce an RF product.

3.2.6 | Continuous/fat-removed/atmospheric

The 'low-temperature rendering system' involved mincing the ABP to <20 mm. The minced ABP was then pumped into a vessel (coagulator), which heated the material to 95°C. The heated material was then pressed, dried in a continuous disc drier, cooled and milled to produce MBM. The liquid fraction, containing RF and water was then centrifuged to separate out the RF product.

3.3 | Process dynamics

In addition to characterising rendering systems, the survey highlighted the key process parameters that could potentially affect the ability of rendering systems to inactivate TSE agents. These were ABP particle size, fat treatment, process temperature and transit time. The ABP particle size influenced the surface area of material subject to processing conditions and the degree of heat penetration. Within rendering systems, particle size reduction (mincing) was controlled by altering the gap between the mincer anvils (anvil gap). Considerable variation in particle size was found to exist both within and between systems. In order to account for this, the SVC TSE Working Group agreed to assign a typical particle size to each rendering system. The addition or removal of RF during processing might also influence process dynamics. Added fat could potentially act as a lubricant within the system such that 'added-fat' systems would have faster and 'fat-removed' systems would have slower transit times, respectively. In addition, the process temperature within different rendering systems was also poorly characterised.

Typically, only one temperature was quoted for each rendering system. This was either the temperature of the rendered product exiting the system, or the temperature recorded by the manufacturer's *in situ* temperature probes. However, these were not necessarily in contact with the substrate.

Perhaps the greatest level of uncertainty regarding the ability of rendering systems to inactivate TSE agents related to transit time. Attempts to predict transit times mathematically from engineering data such as fluid volumes and pump flow rates were only able to estimate mean transit times, not the minimum considered important by the SVC TSE Working Group. It was agreed that transit times could potentially be measured using markers like those used to measure the rate of passage of dietary components through the digestive tract of animals (Uden et al., 1980). The technique involves mordanting (or binding) an indigestible marker (e.g., Chromium) to the dietary component in question (e.g., fibre). The mordanted component is then fed to the animal and samples collected from a point within the digestive tract, or in the faeces. The samples are then analysed for the marker and plotted against time to give the minimum and mean rate of passage. However, in order to apply this technique to rendering systems, a suitable marker and carrying component would need to be identified. The marker chosen would need to be inert, absent from ABP, insoluble in water and easy to measure. Manganese dioxide (MnO_2) was considered to meet these criteria. In addition, the carrying component would have to reflect the rate of passage of ABP through the rendering system. As the solid fraction of raw ABP was essentially bone-rich (>75%) and MBM was thought to be the most likely vector for the BSE agent (Wilesmith et al., 1988), bone was considered to be the most appropriate carrying component. However, bone proved difficult to separate from the ABP and mordant. Therefore, a substitute to bone was developed which consisted of sand, cement and MnO_2 as a marker. This was mixed and formed into balls (30 mm diameter) prior to baking in an oven to produce briquettes which had the same bulk density as bone and when passed through the anvil breakers produced material with the same particle distribution (Table 3). To date, these briquettes are still used as part of the validation process for rendering systems.

TABLE 3 Characteristics of bone and the marker briquettes used to quantify the transit time of animal by-products (ABP) through rendering systems, after particle size reduction (mincing) through the anvil breakers

Characteristic	Bone	Briquettes
Solubility (%)	<1.0	<1.0
Bulk density (kg/l)	795	805
Particle size (%)		
>30 mm	0	0
10–30 mm	37	41
2–10 mm	39	38
<2 mm	9	8

The briquettes were used to determine the transit time of ABP through the different rendering systems. They were introduced into each system when the process was operating under steady state conditions. Three test runs were completed for each system, during which the critical process parameters were monitored. The minimum transit time was defined as the time at which the Mn concentration reached three times the baseline followed by two consecutive increases. The transit time studies confirmed that each system had a very different transit time profile, with the 'continuous/added-fat/vacuum' system having a minimum transit time of 10 min (Figure 3) and the 'continuous/fat-removed/atmospheric' system having a minimum transit time of 60 min. There was also considerable day-to-day variation within three of the systems, although the SD around the minimum transit time was relatively low. The identification of key process parameters (Table 4), together with data from these transit time studies, enabled the SVC TSE Working Group to formulate protocols for subsequent pilot-scale TSE inactivation trials (BSE Inquiry, 2000).

3.4 | TSE inactivation trials

Two TSE inactivation trials were conducted to investigate the ability of rendering systems to inactivate both the BSE and scrapie agents. In order to do this, it was necessary to design and build pilot scale rendering systems to replicate the key process parameters found in commercial rendering plants (Woodgate, 1994) (Table 4). Full details of both the BSE and scrapie inactivation trials are published by Taylor et al. (1995, 1997), respectively. In summary, infected cattle or sheep brains were collected, minced to 10 mm and blended with ABP in a 1:10 ratio prior to processing through the pilot scale rendering systems. Samples of the rendered product were then collected and pressed to produce MBM and RF, which were then sent to the Institute of Animal Health Neuropathogenesis Unit (NPU), Edinburgh, for bioassay of infectivity of the TSE agent using mice. Positive or negative results indicated whether TSE infectivity was confirmed or not (Table 5). Infectivity titres (ID^{50}) were also calculated following serial dilution of the MBM used in the bioassay. The results of the BSE inactivation trial confirmed that one system ('continuous/added-fat/vacuum') was ineffective in reducing the infectivity of the BSE agent given the minimum retention time, whilst the other systems appeared to be more effective. However, owing to partial removal of the cattle brain tissue (approximately 10%) collected for histopathology, the initial infectivity of the MBM used in the BSE inactivation trial was lower than expected and the results were treated with some caution. The temperature and time profiles of the three continuous rendering systems that could potentially inactivate the BSE agent are presented in Table 6. Importantly, these data were subsequently used to develop validation methodology and draft EU legislation (Taylor & Woodgate, 2003). The initial level of infectivity in MBM produced from sheep brain material was significantly higher and therefore the inactivation challenge greater. The scrapie trial subsequently confirmed that only the 'batch/as-received/hyperbaric' system was able to inactive the TSE agent to below detectable levels.

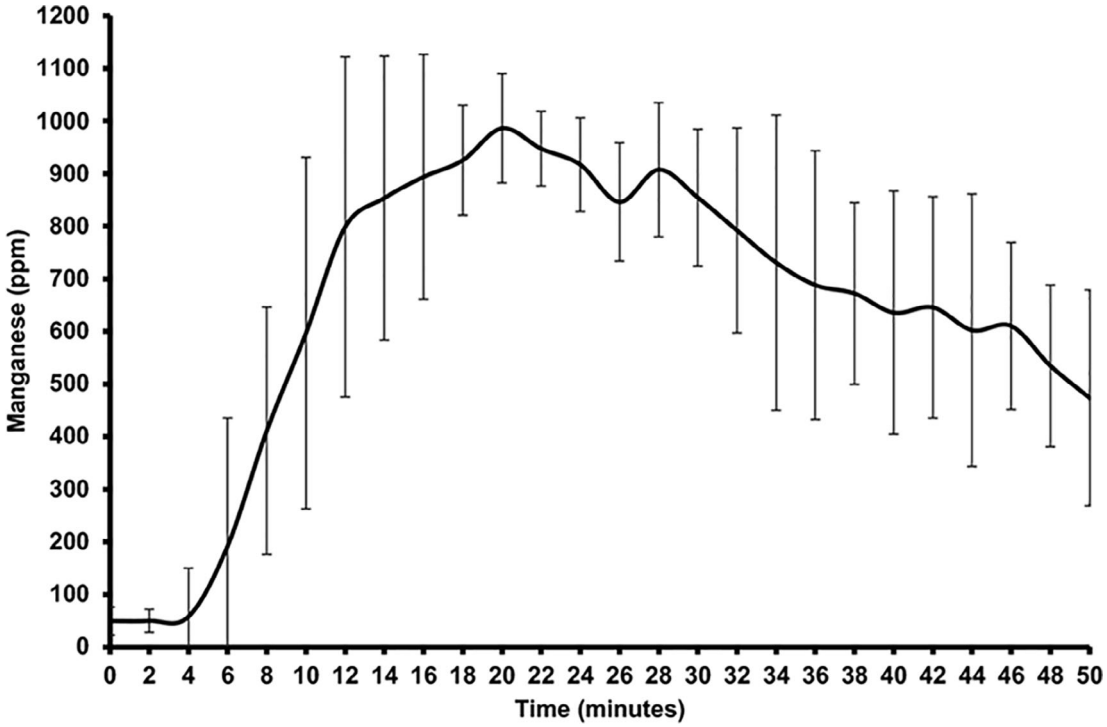

FIGURE 3 Example transit time test for the 'continuous/added-fat/vacuum' rendering system (error bars indicate ±1.0 SD)

TABLE 4 Key process parameters for the six rendering systems operating in the European Union prior to the bovine spongiform encephalopathy (BSE) epidemic in 1986

Rendering system	Minimum transit time (min)	Mean transit time (min)	Minimum end temperature (°C)	Maximum end temperature (°C)	Anvil gap (mm)
Batch/as-received/atmospheric	150	150	120	120	150
Batch/as-received/hyperbaric	20	40	135	145	30
Continuous/added fat/vacuum	10	40	125	125	10
Continuous/as-received/atmospheric	50	125	125	140	30
Continuous/added fat/atmospheric	30	120	140	140	30
Continuous/fat removed/atmospheric	60	240	120	120	20

4 | INITIAL LEGISLATIVE DEVELOPMENTS

The European Commission reacted to the BSE crisis by developing new ABP processing regulations. A recognition that there were different levels of 'risk' associated with different types of ABP resulted in the publication of Council Directive No. 90/667 (Council Directive, 1990). In this, low-risk and high-risk ABP were defined, together with appropriate processing standards. However, this was only considered to be a short-term regulation, to be adapted or replaced depending on the results of the TSE inactivation trials. Subsequently, Commission Decision No. 92/562 introduced the concept of critical control points (CCPs) into EU rendering regulations (Commission Decision, 1992). Each rendering system was described by a flow chart showing the key process parameters (Table 4 and Figure 2). In effect these early legislative developments proved to be staging points in the development of more complex ABP regulations, many arising from the results of the subsequent TSE inactivation trials. When the inability of the 'continuous/added-fat/vacuum' system to inactivate the BSE agent was confirmed (Taylor et al., 1995), the system was immediately banned (Commission Decision No. 94/382). Within this same regulation all other continuous systems were approved subject to validation of key process parameters as determined in the TSE inactivation trials (Table 6). However, when the scrapie inactivation trial (Taylor et al., 1997) confirmed that none of the rendering systems were able to completely inactivate the scrapie agent a further regulation was approved (Commission Decision No. 96/449), which stipulated that all mammalian ABP must be processed at 3 bars (absolute) pressure in excess of 133°C for a minimum of 20 min (Commission Decision, 1996).

Rendering system	Minimum transit time (min)	Infectivity titre (ID^{50})	
		BSE[a]	Scrapie[b]
Untreated TSE infected material		1.7	4.1
Batch/as-received/atmospheric	150	Negative	1.6
Batch/as-received/hyperbaric	20	Negative	Negative
Continuous/added fat/vacuum	10	1.6	Positive
Continuous/as-received/atmospheric	50	Positive	Positive
Continuous/added fat/atmospheric	30	Negative	Positive
Continuous/fat removed/atmospheric	60	Negative	Positive

Abbreviation: BSE, bovine spongiform encephalopathy.
[a]Taylor et al. (1995).
[b]Taylor et al. (1997).

TABLE 5 Summary of the main results from the transmissible spongiform encephalopathy (TSE) inactivation trials conducted by the Institute of Animal Health, Neuropathogenesis Unit (NPU), Edinburgh

Rendering system	>80°C	>100°C	>110°C	>120°C	>130°C
Continuous/as-received/atmospheric		95	55	13	
Continuous/added fat/atmospheric		16	13	8	3
Continuous/fat removed/atmospheric	120	60			

TABLE 6 Temperature and time profiles (minutes) of the continuous rendering systems thought to inactivate bovine spongiform encephalopathy (BSE) following the inactivation trial (Taylor et al., 1995)

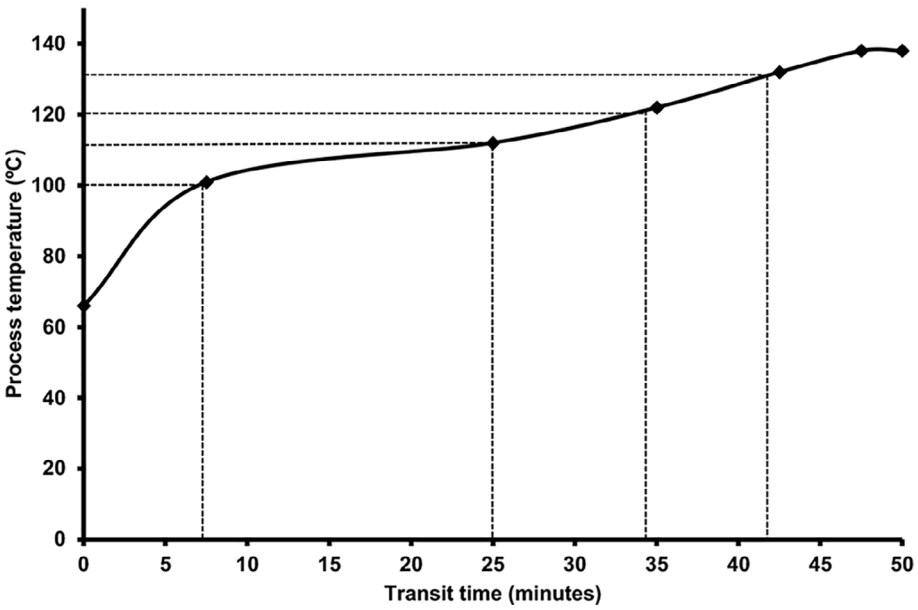

FIGURE 4 Representation of a validation graph used to calculate the minimum time animal by-products were exposed to key temperatures during the rendering process (100–110°C = 17.5, 110–120°C = 10.0 and 120–130°C = 7.0 min)

With the introduction of Commission Decisions 92/562 and 94/382, the rendering industry was required to develop a process to validate rendering systems under operational conditions (Commission Decision, 1992, 1994). The approach adopted was to combine the determination of minimum transit time with the temperature profile of the system under steady state conditions. For each system, a validation test was conducted, with the results being used to produce a validation graph (Figure 4). The x-axis represented both the length of the system (0–1.0) and the minimum transit time (minutes) as determined using the method described previously. The *y*-axis represented process temperature (°C) measured using thermocouples introduced at specific points in the system. The minimum times above key temperatures (e.g., 100, 110, 120, 130°C) were then calculated from the graph. If the system met the process parameters as specified in Table 6 it was approved, subject to specific operating conditions. However, if under normal operation one of these operating conditions was not met, the process was stopped, and the relevant condition corrected before re-starting. Any rendered products produced during this period were re-processed as raw ABP (SVC, 1994). The requirement for process validation and CCPs, first introduced in Commission Decision 94/382 remain in force today in the form of Commission Regulation No. 142/2011 (Commission Regulation (EU), 2011).

5 | CURRENT LEGISLATION

On 20 March 1996 the Secretary of State for Health, Stephen Dorrell pronounced, 'there was almost certainly a link between BSE in cattle and new variant CJD in young adults' (BSE Inquiry, 2000). At the same time, the Spongiform Encephalopathy Advisory Committee (SEAC) minutes of 16 March 1996 noted that 'The Committee agreed to recommend that the use of mammalian MBM in feed for farm animals should be prohibited'. Subsequently, the BSE Amendment Order 1996 (Order, 1996) was published bringing the UK feed ban into effect. The assertion that BSE was linked to a human disease resulted in recognition of the fact that the rendering industry was intricately linked to the food supply chain and the imposition of further regulatory controls on both the rendering industry and food supply chain. Consequently, the European Commission agreed three main themes underpinning subsequent ABP risk reduction legislation, that were, 'safe sourcing', 'safe processing' and 'safe use' (Regulation [EC] 178/2002) (Regulation (EC), 2002a). This regulation also laid down the legal basis for formation of the European Food Safety Authority (EFSA) and confirmed that the rendering industry was an important part of the 'food chain'. In practice, the regulations that ensued focussed on the risk associated with different categories of ABP, processing methods and the uses of rendered products including disposal or use in animal feeds. Two other landmark regulations were approved inter alia within a few months of each other, Regulation (EC) No. 999/2001 and Regulation (EC) No. 1774/2002. The former addressed the use of ABP in animal feeds and the latter dealt with categorisation of ABP and associated processing standards. Both regulations were designed to complement each other with the aim of controlling BSE in the first instance and then, by future amendment of the regulations, allowing for a limited reintroduction of animal proteins into animal feeds. Regulation 999/2001 confirmed the feed ban for animal proteins and introduced the concept of specified risk material (SRM) which represented tissues from ruminant animals (cattle, sheep and goats) considered to present the greatest risk of TSE transmission. These were termed Category 1 ABP and were required to be removed from animals slaughtered for human consumption and disposed of by incineration. In practice, this meant rendering in a dedicated process plant and disposal of the rendered products (MBM and RF) by combustion in steam raising boilers or power generation plants. In practice, Category 1 and 2 ABP were processed together with the resultant products being downgraded to Category 1. Regulation 1774/2002 defined different categories of ABP according to TSE and other risks (Categories 1–3) and introduced a ban on the use of open burning or on-farm burial as methods of ABP disposal except in emergency situations. In addition, appropriate processing conditions for each category of ABP and their potential uses were defined. In essence, rendered products derived from Category 1 (mainly SRM) and Category 2 (mainly deadstock) ABP were prohibited as ingredients in farm animal feeds. However, the use of PAP from Category 3 was approved subject to strict controls, such as no intraspecies recycling. Many of the previous legislative requirements, including those associated with system validation and hazard analysis and critical control point (HACCP) controls, were consolidated within Regulation (EC) No. 1774/2002. However, this regulation has now been superseded by Regulation (EC) No. 1069/2009 and its implementation text (Regulation (EC), 2009, Commission Regulation (EC) No. 142/2011), although the purpose and objectives of the new joint regulations effectively remain the same as the 2002 regulation.

6 | MARKET ADJUSTMENTS

As a consequence of the BSE epidemic, the market for bovine (beef) and rendered products collapsed, the former resulting from falling consumer confidence and the latter resulting from a variety of restrictions placed on the use of rendered products. The EU ban on use of animal-derived proteins in animal feeds (Regulation [EC] No. 999/2001) effectively eliminated the market for MBM and other animal proteins. As a result, MBM became a very undesirable commodity and its value dropped from approximately £150 per tonne to close to zero (A. C. Scott, 2017, personal communication). With no viable markets for rendered products the UK Government (and some EU countries) intervened with financial support to ensure that the rendering industry could continue to operate and provide a service to the livestock and meat industries. However, following the loss of markets for rendered products the rendering industry was forced to change its business model and the costs associated with ABP processing were passed down the chain with the ultimate recipients, farmers, receiving lower prices for their livestock. At the same time, the rendering industry sought to develop export markets for UK-derived MBM and during the late 1990s and early 2000s significant quantities of MBM were exported, mainly to the Far East (Narrod & Otte, 2001). However, this was soon curtailed by the Office Internationale des Epizooties (OIE) who in 1997 began to develop global regulations governing the international trade in animals and animal-derived products (OIE, 1999). In addition, many non-EU countries started to introduce regulations governing rendering processes, both to harmonise veterinary procedures and to prevent the 'dumping' of rendered products that were banned in their country of origin.

Although the BSE Amendment Order 1996 (Order, 1996) and Regulation (EC) No. 999/2001 banned the use of animal-derived protein in animal feed it also provided the option for the ban to be lifted if specific control conditions, such as prevention of intraspecies recycling, could be satisfied in the future (Regulation (EC) No. 1744/2002). In 2005, a quantitative risk assessment confirmed that if animal proteins were to be included in animal feeds in compliance with EU regulations prohibiting the use of ruminant protein and banning the intraspecies recycling of nonruminant protein, the risk of a new BSE epidemic was negligible (European Food Standards Agency (EFSA), 2005). Effective implementation of the legislation required the development of techniques for the identification of ruminant protein. In 2012, a polymerase chain reaction (PCR) method for the determination of ruminant protein in complete feeds was validated (Fumière et al., 2012) and subsequently approved by Commission Regulation

(EC) No. 51/2013 (Commission Regulation (EC), 2013b). At the same time, Commission Regulation (EC) No. 56/2013 authorising the use of Category 3 nonruminant PAP in aqua feeds was also approved (Commission Regulation (EC), 2013c). More recently, the 'relaxation' of EU legislation governing ABP has continued with approval of Commission Regulation (EC) No. 893/2017 authorising the export of Category 3 ruminant PAP to non-EU countries under strictly controlled conditions of confirmed provenance and secure transportation (Commission Regulation (EC), 2017). The concept behind Commission Regulation (EC) 893/2017 was to make ruminant PAP available to non-EU countries where there might, 'in principle', be a demand for ruminant animal proteins in pig and poultry diets. However, within the EU it is unlikely that ruminant PAP will be authorised for use in pig and poultry diets in the short to medium term because of limited segregation between ruminant and nonruminant feed production by most manufacturers.

7 | NEW MARKETS FOR RENDERED PRODUCTS

In response to changes in the business environment the rendering industry sought to 'add value' to both ABP and rendered products by conducting research to support the development of new markets. The fact that UK and EU legislation required that Category 1 (and by association Category 2) rendered products must be destroyed by incineration (Order, 1996) (EU Regulation (EC) No. 999/2001) meant that rendered products could potentially be used as biofuels which could be used to generate electricity and offset fossil fuel use in other systems. The main route for disposal of Category 1 MBM in the UK is combustion in fluidised bed combustion power plants, with a resultant reduction in the use of fossil fuels. Similarly, the use of Category 1 RF as a fuel in Category 3 rendering plants could reduce the greenhouse gas (GHG) emissions associated with Category 3 rendered products. The GHG emissions of Category 1 RF are −0.77 kg CO_2^e kg^{-1}. Consequently, when used as a fuel in Category 3 rendering plants the GHG emissions of Category 3 RF and PAP are 0.15 and 0.15 kg CO_2^e kg^{-1}, respectively (Ramirez et al., 2012). The use of Category 3 rendered products in other systems has the potential to significantly reduce GHG emissions. For example, Category 3 RF has the potential to replace other fat sources, such as palm oil in the oleo-chemical and aqua-feed industries, which has GHG emissions of 2.1–2.6 kg CO_2^e kg^{-1} (Schmidt, 2010). Similarly, Category 3 PAP has the potential to replace soya bean meal in animal diets, which has GHG emissions of 0.72 kg CO_2^e/kg (Dalgaard et al., 2008).

Probably the most important research imperative concerning rendered products related to their reintroduction into animal feeds. Following the EU insistence that no intraspecies recycling should be allowed (Regulation (EC) No. 1774/2002), research focussed on species-specific methods, including PCR for detecting PAP in animal feeds. Two major EU research projects STRATFEED (Dardenne, 2005) and SAFEED-PAP (Jorgensen & Baeten, 2013) confirmed that significant DNA degradation occurred during the rendering process. The challenge of using degraded DNA as the starting point for method development meant that the reference materials also had to be produced under the same conditions (Woodgate et al., 2009). The development and validation of a PCR method for the detection of ruminant PAP in animal feeds (Fumière et al., 2012) has paved the way for changes in legislation allowing the reintroduction of nonruminant PAP into aqua feeds (Commission Regulation [EU] No. 56/2013). As a result, the EU Feed Catalogue (Commission Regulation [EU] No. 2017/1017) now refers to PAP and includes the statutory declaration required if such materials are incorporated into animal feeds (Commission Regulation (EC), 2013a). An updated qualitative risk assessment (European Food Standards Agency (EFSA), 2018) has recently reconfirmed the negligible risk associated with use of animal proteins in animal feeds if used in compliance with EU legislation, including the use of porcine PAP in poultry diets and poultry PAP in pig diets. In addition, it sets out the criteria required for a PCR test such that a 'technical zero' can be reported for detection of species-specific PAPs. Trials are currently underway to evaluate methods of detecting both porcine and poultry PAP and the successful validation of species-specific detection methods should pave the way for reintroduction of porcine PAP into poultry feeds and poultry PAP into porcine feeds. However, it is important to recognise that the nutritional characteristics of modern PAPs are probably very different to those of MBM prior to the BSE crisis or MBM produced in other parts of the world.

As it was generally anticipated that changes in EU legislation would initially permit the inclusion of nonruminant PAP into aqua-feed research has tended to focus on the replacement of fishmeal and vegetable protein sources in aqua feeds. Davies et al. (2009) reported protein digestibility coefficients for nonruminant PAP of 0.85, 0.79 and 0.78 in European sea bass, Gilthead sea bream and Turbot, respectively. In addition, Hatlen et al. (2015) reported that poultry PAP could effectively replace 0.5 of the fishmeal in the diet of Atlantic salmon without reducing performance. Similarly, Kumar et al. (2017) reported that PAP and soya bean meal were equally effective in replacing up the 0.6 of the fishmeal in Catfish diets and Davies et al. (2019) reported that poultry PAP could effectively replace 0.75 of the fishmeal in juvenile gilthead sea bream diets. The inclusion of PAP in aqua feeds may also confer positive benefits in terms of gut health (Liland et al., 2015). To date, little research has been conducted on the inclusion of nonruminant PAPs in the diets of other species, although some work has been reported with laying hens (Van Krimpen et al., 2010). However, with the potential reintroduction of nonruminant PAPs there is an urgent need for further research and feed characterisation to ensure that they can be successfully incorporated into pig and poultry diets, whilst also considering their potential impact on both human and animal health and the environment.

8 | CONCLUSIONS

The BSE epidemic in 1986 highlighted the importance of the rendering industry as a key component in the food supply chain and

emphasised the fact that economic imperatives, resulting in changes in production methods can have unforeseen consequences in relation to both animal and human health. Through the characterisation of rendering processes and shaping of EU legislation the rendering industry has played a crucial role in the elimination of BSE. Subsequent research initiatives have continued to add value to rendered products such that the rendering industry continues to operate and provide both a valuable service and products to the livestock and meat industries. With the increasing demand for animal products and sustainable intensification of production systems, the nutritional, environmental and economic characteristics of PAPs mean that they represent valuable ingredients for inclusion in animal feeds. The EU has adopted a more cautious approach than the rest of the world regarding the utilisation of animal proteins in animal feeds, which limits the market for and economic value of rendered products. Recent developments in detection and quantification techniques have paved the way for legislative changes allowing the safe reintroduction of nonruminant PAPs into aqua feeds, and successful validation of species-specific detection methods may soon facilitate their reintroduction into pig and poultry feeds. However, resistance from key stakeholders (processors, retailers and consumers) in the food chain remains a significant challenge that must be overcome before their full potential can be realised. Further research is required to characterise modern PAPs and to ensure their appropriate, safe and acceptable inclusion in animal diets.

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REFERENCES

Agricultural Research Council (ARC) (1984) *The nutrient requirements of ruminant livestock (supplement 1). Report of the Protein Group of the Agricultural Research Council Working Party on the nutrient requirements of ruminants*. Slough, England: Commonwealth Agricultural Bureaux.

Berge J. L. (1986) Energy conservation in continuous rendering. In A. R. Baldwin. (Ed.), *Proceedings of world conference on emerging technologies in the fats and oils industry*, pp. 133–134. Champaign, IL: American Oil Chemists Society.

Brown P., Will R. G., Bradley R., Asher D. M., & Detwiler L. (2001) Bovine spongiform encephalopathy and variant Creutzfeldt–Jakob disease: background, evolution and current concerns. *Emerging Infectious Disease*, *7*, 6–16.

BSE Inquiry (2000) *The report, evidence and supporting papers (House of Commons Papers)*. London, England: Stationery Office Books.

Burnham F. A. (1978) *Rendering: The invisible industry*, Fallbrook, CA: Aero.

Commission Decision (1992) Commission Decision of 17 November 1992 on the approval of alternative heat treatment systems for processing high-risk material (92/562). *Official Journal of the European Communities*, *L359*, 23.

Commission Decision (1994) Commission Decision of 27 June 1994 on the approval of alternative heat treatment systems for processing animal waste of ruminant origin, with a view to the inactivation of spongiform encephalopathy agents (94/382). *Official Journal of the European Communities*, *L172*, 25.

Commission Decision (1996) Commission Decision of 18 July 1996 on the approval of alternative heat treatment systems for processing animal waste with a view to the inactivation of spongiform encephalopathy agents (96/449). *Official Journal of the European Communities*, *L184*, 43.

Commission Regulation (EC) (2013a) Amending regulation (EU) 68 on the catalogue of feed materials (2017/1017). *Official Journal of the European Communities*, *L159*, 97–99.

Commission Regulation (EC) (2013b) Commission Regulation (EC) of 16 January 2013 on amending Regulation (EC) No. 152/2009 as regards the methods of analysis for the determination of constituents of animal origin for the official control of feed (51/2013). *Official Journal of the European Communities*, *L184*, 43.

Commission Regulation (EC) (2013c) Commission Regulation (EC) of 16 January 2013 on amending Annexes 1 and IV to Regulation (EC) No. 999/2001 of the European Parliament and of the Council laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies (56/2013). *Official Journal of the European Communities*, *L21*, 3.

Commission Regulation (EC) (2017) Amending Annexes I and IV to Regulation (EC) No. 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No. 142/2011 as regards the provisions on animal protein (No. 893). *Official Journal of the European Communities*, *L138*, 92–116.

Commission Regulation (EU) (2011) Commission Regulation (EU) of 25 February 2011 on implementing Regulation (EC) No. 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption (142/2011). *Official Journal of the European Communities*, *L54*, 1.

Council Directive (1990) Council Directive of 27 November 1990 on laying down the veterinary rules for the disposal and processing of animal waste, for its placing on the market and for the prevention of pathogens in feedstuffs of animal or fish origin and amending Directive 90/425/EEC (90/667/EEC). *Official Journal of the European Communities*, *L363*, 0051–0060.

Crawshaw R. (1995) Meat and bone meal: A review of its nutritional qualities for pigs. *Feed Compounder*, *15*, 14–19.

Dalgaard R., Schmidt J., Halberg N., Christensen P., Thrane M., Penhue W. A. (2008) LCA of soya bean meal. *International Journal of Life Cycle Assessment*, *13*, 240.

Dardenne P. (2005) *Strategies and methods to detect and quantify mammalian tissues in feedstuffs*. Brussels, Belgium: European Commission.

Davies S. J., Gouveia A., Laporte J., Woodgate S. L. (2009) Nutrient digestibility profile of premium (category III grade) animal protein by-products for temperate marine fish species (European sea bass, gilthead bream and turbot). *Aquaculture Research*, *40*, 1759–1769.

Davies S. J., Laporte J., Gouveia A., Salim H. S., Woodgate S. L., Hassaan M. S., El-Horoun E. R. (2019) Validation of processed animal proteins (mono-PAPS) in experimental diets for juvenile gilthead sea bream (*Sparus aurata* L.) as primary fish meal replacers within a European perspective. *Aquaculture Nutrition*, *25*, 225–238.

European Food Standards Agency (EFSA) (2005) Opinion on the quantitative risk assessment of the animal BSE risk posed by meat and bone meal with respect to the residual BSE risk. *EFSA Journal*, *257*, 1–30.

European Food Standards Agency (EFSA) (2018) Updated quantitative risk assessment (QRA) of the BSE risk posed by processed animal protein (PAP). *EFSA Journal*, *16*, e05314.

Fumiere, O., Marien, A., & Berben, G. (2012). *EURL-AP implementation test*. Gembloux, Belgium: Walloon Agricultural Research Centre. Retrieved from http://eurl.craw.eu/img/page/interlaboratory/EURL_AP_PCR_ILS_2012_final_version.pdf

Hatlen B., Jakobsen J.V., Crampton V., Alm M., Langmyher E., Espe M., Hevroy E.M., Torstensen B.E. (2015) Growth, feed utilisation and endocrine responses in Atlantic salmon (Salmo salar) fed diets added poultry by-product meal and blood meal in combination with poultry oil. *Aquaculture Nutrition*, *21*, 714–725.

Jorgensen J. S., Baeten V. (2013) . *Detection, identification and quantification of processed animal proteins in feedstuffs*. Namur, Belgium: Les presses Universitaires de Namur.

Kimberlin R.H. (1993) *Bovine spongiform encephalopathy*. Rome, Italy: Food and Agriculture Organisation.

Kudra T., Mujumdar A. S. (2001) The Carver-Greenfield process. In *Advanced drying technologies*, pp. 267–270. New York, NY: Marcel Dekker.

Kumar S., Sándor J., Nagy Z., Fazekas G., Havasi M., Sinha A. K., DeBoeck G., Gál D. (2017) Potential of processed animal proteins versus soybean meal to replace fishmeal in practical diets for European catfish (*Silurus glanis*): growth response and liver gene expression. *Aquaculture Nutrition*, *23*, 1179–1189.

Liland N. S., Hatlen B., Talke H., Venegas C., Espe M., Torstensen B. E., Waagbø R. (2015) Including processed poultry and porcine by-products in diets high in plant ingredients reduced liver TAG in Atlantic salmon (*Salmo salar*). *Aquaculture Nutrition*, *21*, 655–669.

Ministry of Agriculture Fisheries and Food (MAFF) (1986) . *Feed composition: UK tables of feed composition and nutritive value for ruminants*. Marlow, England: Chalcombe.

Narrod C., Otte J. (2001) Global trade in livestock products and by-products. In *Proceedings of the joint WHO/FAO/OIE technical consultation on BSE: Public health, animal health and trade, 10–14 June 2001*. Paris, France: WHO/FAO/OIE.

OIE (1999) *Terrestrial animal health code*. 8th edn. Paris, France: World Organisation for Animal Health (OIE).

Order (1981) *The diseases of animals (protein processing) order 1981. Statutory instruments 1981*. London, England: Her Majesty's Stationery Office.

Order (1996) *The bovine spongiform encephalopathy (amendment) order 1996*. London, England: Her Majesty's Stationery Office.

Ramirez A. D., Humphries A. C., Woodgate S. L., Wilkinson R. G. (2012) Greenhouse gas life cycle assessment of products arising from the rendering of mammalian animal by-products in the UK. *Environmental Science and Technology*, *46*, 447–453.

Regulation (EC) (2001) Regulation (EC) 22 May 2001 of the European Parliament and of the Council of laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies (999/2001). *Official Journal of the European Communities*, *L147*, 1.

Regulation (EC) (2002a) Regulation (EC) of the European Parliament and of the Council laying down the general principles and requirements of food, establishing the European Food Safety Authority and laying down procedures in matters of food safety (No. 178). *Official Journal of the European Communities*, *L31*, 1–24.

Regulation (EC) (2002b) Regulation (EC) of the European Parliament and of the Council of 3 October on laying down health rules concerning animal by-products not intended for human consumption (1774/2002). *Official Journal of the European Communities*, *L273*, 1.

Regulation (EC) (2009) Regulation (EC) 21 October 2009 of the European Parliament and of the Council of on laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No. 1774/2002 (animal by-products regulation) (No. 1069/2009). *Official Journal of the European Communities*, *L300*, 1.

Schmidt J.H. (2010) Comparative life cycle assessment of rapeseed oil and palm oil. *International Journal of Life Cycle Assessment*, *15*, 183–197.

SVC. (1994). Detailed procedures for the validation of rendering processes described in Commission Decision 92/562/EEC for the processing of ruminant material in application of Commission Decision 94/382/EEC. Prepared by an expert sub-group of the Scientific Veterinary Committee.

Taylor D. M. (1990) Decontamination of scrapie like agents. In *Subacute spongiform encephalopathies*, pp. 153–159.Eds R. Bradley, M. Savey and B. Marchant. Dordrecht, Netherlands: Kluwer Academic.

Taylor D. M., Woodgate S. L. (2003) Rendering practices and inactivation of transmissible bovine spongiform encephalopathy agents. *Revue Scientifique et Techniques de l Office International des Epizooties*, *22*, 297–310.

Taylor D. M., Woodgate S. L., Atkinson M. J. (1995) Inactivation of the bovine spongiform encephalopathy agent by rendering procedures. *Veterinary Record*, *137*, 605–610.

Taylor D. M., Woodgate S. L., Fleetwood A. J., Cawthorne R. J. G. (1997) Effect of rendering procedures on the scrapie agent. *Veterinary Record*, *141*, 643–649.

Uden P., Colucci P. E., Van Soest P. J. (1980) Investigation of chromium, cerium and cobalt as markers in digesta. Rate of passage studies. *Journal of the Science of Food and Agriculture*, *31*, 625–632.

Van Krimpen M. M., Veldkamp T., Binendijk G. P., de Veer R. (2010) Effect of four processed animal proteins in the diet on digestibility and performance in laying hens. *Poultry Science*, *89*, 2608–2616.

Wang X., Parsons C. M. (1998) Effect of raw material source, processing systems and processing temperatures on amino acid digestibility of meat meals. *Poultry Science*, *77*, 834–841.

Wells G. A. H., Scott A. C., Johnson C. T., Gunning R. F., Hancock R. D., Jeffrey M., Dawson M., Bradley R. (1987) A novel progressive spongiform encephalopathy in cattle. *Veterinary Record*, *121*, 419–420.

Wilesmith J. W., Wells G. A. H., Cranwell M. P., Ryan J. B. M. (1988) Bovine spongiform encephalopathy: epidemiological studies. *Veterinary Record*, *123*, 638–644.

Woodgate S. L. (1994) Rendering systems and BSE deactivation. Proceedings of the European Association of animal production. *Livestock Production Science*, *38*, 47–50.

Woodgate S. L., Van Der Veen J. T. (2004) The use of fat processing and rendering in the European Union animal production industry. *Biotechnology, Agronomy, Society and Environment*, *8*, 283–294.

Woodgate S. L., Van den Hoven S., Vaessen J., Margry R. (2009) Control tools to detect processed animal proteins in feed and in animal by-products: specificity and challenges. *Biotechnology, Agronomy, Society and Environment*, *13*, 9–13.

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