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SURVEYING SELECTED EUROPEAN FEED AND LIVESTOCK PRODUCTION CHAINS FOR FEATURES ENABLING THE CASE-SPECIFIC POST-MARKET MONITORING OF LIVESTOCK FOR INTAKE AND POTENTIAL HEALTH IMPACTS OF ANIMAL FEEDS DERIVED FROM GENETICALLY MODIFIED CROPS

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Abstract

This review, which has been prepared within the frame of the European Union (EU)-funded project MARLON, surveys the organisation and characteristics of specific livestock and feed production chains (conventional, organic, GM-free) within the EU, with an emphasis on controls, regulations, traceability, and common production practices. Furthermore, an overview of the origin of animal feed used in the EU as well as an examination of the use of genetically modified organisms (GMOs) in feed is provided. From the data, it shows that livestock is traceable at the herd or individual level, depending on the species. Husbandry practices can vary widely according to geography and animal species, whilst controls and checks are in place for notifiable diseases and general health symptoms (such as mortality, disease, productive performance). For feeds, it would be possible only to make coarse estimates, at best, for the amount of GM feed ingredients that an animal is exposed to. Labeling requirements are apparently correctly followed. Provided that confounding factors are taken into account, practices such as organic agriculture that explicitly involve the use of non-GM feeds could be used for comparison to those involving the use of GM feed.

Keywords:

Livestock, feed production chain, genetically modified crops, post-market monitoring, regulation, traceability

Abbreviations used:

EFSA, European Food Safety Authority; EU, European Union; FEFAC, European Feed Manufacturers' Federation; GM, genetically modified; GMO, Genetically modified organism

Research highlights:

- EU regulations enable tracing of livestock in production chains focusing on animal identification and infectious diseases.
- Structures of different livestock sectors vary within the EU, but production practices are similar for large-scale producers.
- It is not possible to trace all feed in the EU back to the farm of origin, to quantify the distribution and proportion of GMOs.
- Available data indicate the majority of GM feed materials are correctly labelled.
- Organic systems and other certified GMO-free-feed employing practices prohibit the use of GM feed, providing a possibility to examine production chains without the use of GMOs.

1. INTRODUCTION

Since their large-scale commercial introduction in the mid-90s, the cultivation of genetically modified (GM) crops, particularly commodity crops such as soybean, maize, cotton and oilseed rape, have rapidly gained adoption. In 2016, the acreage of these crops planted by farmers worldwide amounted to 185 million hectares, most of which was situated in countries in North and South America, Asia, and Africa, and in Australia. The cultivation of such crops within the European Union (EU) is relatively limited, comprising insect-resistant maize grown particularly in Spain, Portugal, Czech Republic, and Slovak Republic (James, 2016). Notwithstanding this, livestock feeds in the EU may still consist, contain or be produced from GM crops given the considerable imports from non-EU countries.

Before GM crops are allowed to be commercialized as food or feed, they have to undergo regulatory approval in many countries. As part of the regulatory approval procedure, a safety assessment has to be carried out according to the internationally harmonized principles developed under the auspices of the FAO/WHO Codex Alimentarius Commission (Codex alimentarius, 2008). According to these principles, the characteristics of GM crops are compared to those of a conventional counterpart with a history of safe use, including molecular, phenotypic, agronomic, and compositional data. Any differences identified then need to be assessed for their relevance to safety and whether further data are needed to reach a conclusion on the safety of the specific GM crop. Expanding on Codex principles, the approach followed by EU risk assessors are laid down in a detailed guidance developed by the European Food Safety Authority's panel of experts on genetically modified organisms (EFSA GMO Panel) and incorporated into EU legislation (EFSA, 2011; EU, 2013b). Under these rules and guidance, it is foreseen that situations may arise in which post-market monitoring may be part of the requirements for market admission, such as to verify pre-market assumptions.

In order to be prepared for possible post-market monitoring requirements for potential health impacts of future GM feed crops, the European Commission's Seventh Framework Program (FP7) for Research and Technology Development funded the MARLON project with the aim of developing generically applicable tools that could assist applicants in designing and performing post-market monitoring programs (MARLON, 2015). The aim of this review is, as part of the MARLON project, to report the outcomes of a survey of selected livestock and feed production chains. This survey was envisaged to foster insight into the processes on national as well international levels. In this context, the organization of these production chains, the possibility to detect and trace GM feed, and to measure exposure and detect potential health impacts of GM feeds has been reviewed. With this information, researchers within and beyond the project will be able to attune the development of monitoring tools to the particular features of these feed and livestock production chains.

2. LIVESTOCK SECTOR STRUCTURE AND THE POSSIBILITY TO VERIFY ANIMAL HEALTH AND MOVEMENT THROUGHOUT THE PRODUCTION CHAIN

Livestock production straddles a wide range of production animal species, whilst the ones explored in this review specifically include dairy and beef cattle, fish, pig, and meat- and egg-producing poultry. Existing controls, inspections and traceability regimes within the EU were explored to verify if they could provide useful data on GM feed consumption and livestock health for the purpose of monitoring. This included in particular the various kinds of health checks that are already in place along the production chain and which might be amenable to incorporation into a monitoring scheme for potential impacts of animal feed on livestock health. Moreover, it would be important to know if the past of an individual or group of animals can be traced back if diverging health symptoms become apparent. The EU has established basic identification requirements to be followed by the member states to ensure traceability of livestock from birth to slaughter, whilst regulations vary according to the species. Through the web-based Trade Control and Expert System (TRACES) (EC, 2017a), a centralised database run by the European Commission's (EC) Directorate-General for Health and Consumer Protection, TRACES certifies and monitors the trade of animals and animal products. It enables tracking of the movement of animals and products of animal origin from both outside and within the EU and links border inspection posts, allowing for exchange of data, including veterinary related information, between national and community authorities.

For individuals or businesses involved in the trade of animals or animal products within the EU, it is required to register themselves. With regard to transport of livestock animals to, from and within the EU, a register is to be kept with details on the starting date, route, and duration of transport, the animals' supplier and receiver, and disinfection of the vehicles used. Also in this case, records have to be stored for at least three years.

For veterinary products being traded with non-EU counterparts, there are approximately 300 approved border inspection posts in the EU for veterinary and zootechnical checks, which are officially listed (EU, 2009d). Within the EU, slaughterhouse controls cover both ante and post-mortem inspection of food producing animals. In most cases, an official veterinarian has to be present during both inspections. Pigs and poultry can also be inspected before they are put on transport to the slaughterhouse. Special attention is to be given to detection of notifiable diseases, which have to be reported and properly documented. In the case of certain diseases (e.g., transmissible spongiform encephalopathies), mandatory testing is carried out during post-mortem examination. The on-farm inspection before transport will also include examination by the official veterinarian of the animals for general signs of disease as well as use of prohibited substances.

2.1. Poultry meat production: Broilers

Broilers are generally housed intensively in large groups in either environmentally controlled housing or naturally ventilated poultry houses. They are kept loose on litter (*e.g.*, wood shavings, spelt pellets, maize silage), and provided with feed and water via automated systems. Some indoor systems provide outdoor access via runs, small yards and a small percentage of holdings involve completely outdoor systems.

The production of poultry meat involves organised production chains divided into distinct stages and two main models: horizontal and vertical integration. In the horizontal integration model, independent companies are involved in different stages of the chain. For example, breeders, hatcheries, fattening farms, feed mill, and processing plants are run separately. In the vertical integration model, all stages of the production chain (*e.g.* breeding, rearing, hatching, growing, and slaughter) are under the control of one company or integrator. Belgium and the Netherlands have mostly horizontal integration, France, Italy, and Spain, vertical integration, and Germany, both (Van Horne, 2007).

Broiler chicks come from specialised hatcheries, most of which also house parent lines. Eggs are kept in incubators and chicks hatch after approximately 21 days, at which stage they are usually transported to breeding or rearing farms for the second stage of fattening, which may involve different housing densities as well as slaughter ages and weights (Berk, 2008).

Broiler feed, which is mostly in the form of pellets, is compounded from cereals such as wheat and maize and protein rich ingredients such as oilseed meals, pulses, and soya. Fats or oils are added as additional sources of energy and diets are routinely supplemented with a range of additives including amino acids, minerals, vitamins, and medications (*e.g.,* coccidiostats). Nutritional content and rations vary depending on production stage and method. (Berk, 2008; EC, 2000).

Broilers are commonly inspected by a veterinarian two to three times during the fattening period. Inspection includes examination of production records, assessment of mortality rates, assessment of feed quality, and sampling for pathogens if health and performance problems have been found or are suspected.

For poultry farming, all holdings in the EU with greater than 500 chickens kept for meat production are required to maintain documentation for a period of at least three years (EU, 2007a). This documentation encompasses a range of details on the husbandry of these chicken flocks such as breed, numbers of animals introduced, incidence and suspected cause of mortality, and numbers dispatched for sale or slaughter.

At the poultry slaughterhouse, ante-mortem inspection includes checks for proper documentation, external signs of disease, and mortality rate during transportation. The number of carcasses discarded or condemned during slaughter is also noted and recorded in slaughterhouse registers.

2.2. Poultry egg production: Laying hens

The proportion of laying hens in different housing systems (*i.e.*, cage, barn, free range, organic) varies by country. In France, Italy, and Spain, the majority of laying hens are kept in cages while in Germany and the Netherlands, the majority of laying hens are kept in barns. The UK is an exception, with half of the hens being kept as free-range (CIWF, 2013).

The egg production cycle can be divided into two main phases: rearing and laying. Rearing is the stage in which chicks are housed immediately after hatching and before they start to lay eggs. Around 16 to 20 weeks of age, they are transferred to the laying system which can involve cage, barn, or outdoor free-range systems. Hens are kept in these systems until about 72 to 74 weeks of age, when they will have laid approximately 300 eggs. After this time, production decreases and hens are typically sent for slaughter. Poultry are typically offered compound feed consisting of a variety of different ingredients. Ingredients in compound feed can be divided into those that provide energy (*e.g.,* maize grains, maize and wheat milling by-products, molasses, vegetable fats), protein/amino acids (*e.g.,* oilseed meals, fish meal, alfalfa meal) and minerals such as calcium and phosphorus (Chiba, 2014).

General health management strategies for laying hens involve optimisation of husbandry conditions, biosecurity, health monitoring, and prevention of disease and parasites. Daily monitoring of poultry is a key element and includes daily checks of the flock for signs of disease and parasites, as well as sampling of droppings, for example, for the detection of pathogens, such as *Salmonella*, under national control programs (EU, 2003c; EU, 2011a).

In the EU, laying hens are identified and traced at the production-lot level rather than at the individual level. A unique code is assigned to each holding, whilst a similar procedure is applied to eggs, which enables tracing back to the farm where they were produced (EU, 2002b).

2.3. Pork production: Swine

The structure and geographic distribution of pig production throughout the EU is complicated to summarise due to the large variation in the type and size of farms (*e.g.*, small vs. large breeder, fattener, and/or mixed farms) as well as production focus of farm (*e.g.*, breeders, fatteners, mixed). Overall, pig production is concentrated mainly in Denmark, Germany, France, the Netherlands, Poland, and Spain, which have more than two-thirds of breeding pigs. When considering three categories of pigs, piglets, breeding sows, and growing-finishing pigs, 1.7% of pig farms have at least 400 growing-finishing pigs; these farms are concentrated in 12 member states. It is important to note that this low percentage is influenced by the large number of farms in the EU (73%) that rear pigs in units of less than 10 pigs, particularly in Romania, Croatia, Slovenia, Lithuania, and Bulgaria. There is also a substantial intra-EU trade of pigs, involving, for example, almost 18 million animals of less than 50 kg traded in 2011 with Germany as the principal importer of young pigs and Denmark the leading exporter.

Husbandry practices vary according to the stage and purpose of production. The majority of pigs are produced in intensive production systems that house animals in enclosed buildings, while extensive, outdoor farming is typically in organic systems or for holdings raising pigs for their own consumption. On small farms, breeding is usually carried out within the herd and breeding animals are kept or purchased for natural service. Larger, more intensive farms typically practice artificial insemination and take part in breeding schemes (EC, 2014).

Pig holdings can include fattening farms, farms that produce breeding pigs or piglets only, and farms that involve both piglet production and fattening. The production cycle can be broadly divided into two main categories: farrowing and rearing. After weaning, piglets are either reared to be breeding animals or for meat production. For meat production, production can be divided into two phases, *i.e.* the growing and finishing phases. For the growing phase, piglets are moved directly after weaning to a ''nursery''. Six to ten weeks post weaning, they are usually moved again for the fattening period, which lasts for approximately 5 months. At a weight of 100 to 120 kg (6 to 8 months of age), they are sent for slaughter (Agrar-Lexikon, 2013).

Pigs are typically fed mixed rations based upon the stage and purpose of production. Important dietary components include carbohydrates, fibre, and protein. Within Germany, soybean and rapeseed are the most commonly used protein sources (Bavarian State Research Center for Agriculture, 2013).

Standard health practices include the use of the "all-in, all-out" production system, strict disinfection protocols, routine parasite control through use of deworming agents, and prophylactic vaccination. The EU has established regulations for member states regarding the control and monitoring of Salmonella in pigs (EU, 2003c; EU, 2014). At the member state and individual far level, routine veterinary visits and inspections are carried out and records must be kept of treatments carried out (*e.g.*, animals treated, date of treatment, medicines used) as well as mortality data.

Under EU law (EU, 2008a), pigs traded or moved across borders within the EU must be identified and registered. This entails the use of an ear tag or tattoo, the keeping of a register for at least three years with information on the herd at the holding, and registration by a national computer database (EU, 2000). Pigs imported from a third country to be slaughtered in the EU, however, are not required to be identified by a mark if they pass veterinary checks established for animals coming from third countries and if they are slaughtered within 30 days of having passed the veterinary checks (Europa, 2016).

2.4. Bovine milk production: Dairy cattle

Significant variation in dairy cattle husbandry practices exists among member states. Housing systems (*e.g.*, cubicle, tie-stall systems, straw yard systems, and pasture systems) can vary depending on climate, geography, resources, as well as traditions. Additionally, some farms have outdoor grazing only whereas others house cows completely indoors for the entire year or for part of the year.

A typical dairy cow is first bred at an average age of 15-18 months, delivering her first calf at 24 to 27 months and kept in the herd for two to four lactations on average, or until about five to six years of age. Artificial insemination is widely used though practices vary between only artificial insemination and only natural service, and sometimes both. Production and collection of milk is initiated by birth of a calf, and therefore cows are bred regularly, with the aim of producing a calf every 12 to 13 months. Lactation typically lasts 11 to 13 months and spans the period from calving until approximately 60 days before the next calving. To maintain yearly calving, cows are bred around 60 days after calving.

During lactation, cows are usually milked twice a day. On large farms with highly automated systems, cows may be milked up to three times daily. Average daily milk yields range between 20 to 30 kg per cow per day and 7,000 to 8,000 kg per cow per year. At the end of a lactation cycle, cows require a dry period of six to eight weeks when milk production is completely halted before the birth of a new calf.

Newly born dairy calves are usually separated from their mothers immediately after calving, moved to individual stalls, and provided colostrum through hand-held bottles up until the end of the first week of life. Female calves are typically reared on farm as replacements and, after the first week of life, given milk or milk replacer until weaning at approximately 6 to 8 weeks of age. During this time, feed is also provided in the form of grain or forage to promote development of the rumen. After weaning, calves are moved to group housing, where they are kept until a few months before calving at 24 to 32 months of age. At this time, they are introduced to the dairy herd.

Feeding systems are dependent largely on how cattle are kept as well as on feed availability and geography. For example, cows that are predominantly housed indoors are fed forages (hay and silage) and mixed rations, including concentrates; animals kept completely at pasture are usually provided with feed supplements, concentrates in particular.

As regards animal feeds, concentrates usually make up part of the cattle feed rations. Protein sources, such as soy, are largely imported, e.g., from Latin American countries. The majority of maize is locally produced and the remaining part is imported, principally from other EU member states, whilst oats and wheat by-products may be also mainly produced nationally. Besides concentrates used to feed bovines, crops used as forage for feeding are usually grown locally, including alfalfa, maize, rye grass, clover, vetch, and straw. On farms in which animals do not have regular access to pasture, diets commonly consist of a total mixed ration based on silage or hay and concentrates. This contrasts with farms following an extensive system, which base the forage portion of the diet on available pasture and supplement with concentrates at milking time.

Standard health practices in dairy cattle management include reproductive health management, udder health management through the institution of milk hygiene practices, foot health management, parasite control and preventive vaccination. In Spain, for example farmers do not generally have a detailed management plan and reproductive controls are usually carried out by a veterinarian one to two times monthly (Salcedo Diaz, 2004). There is no EU legislation requiring mandatory testing of live cattle for infectious disease. However, some member states (*e.g.*, Spain, United Kingdom) require mandatory testing and control measures for tuberculosis, brucellosis and other important bovine diseases as they are not officially declared free of these diseases (EU, 1964).

For cattle, the identification and registration of bovine animals under EU legislation includes the use of ear tags with individual registration numbers for each individual animal in addition to records being kept at the farm, data entered in a national database system and the use of a cattle passport (EU, 2004b). Starting July 2019, animals may also be tagged electronically, such as via application of an electronic ear tag, ingestion of a ruminal bolus, or injection of a transponder to a young bovine. Animals imported from another EU member state keep the ear tags from their country of origin, whilst animals imported from a third country must have new ear tags placed and a new passport issued. It is not necessary to retag foreign animals that go to a slaughterhouse located within the country of import within 20 days of arrival (EC, 2017b).

2.5. Bovine meat production: Beef cattle

The beef production system is divided into two main sectors, *i.e.* the production and fattening of the calves. Whilst these two sectors are integrated in most European countries,, with farmers raising calves on their own farm, they are separate in others such as Spain, where they are located in different areas of the country.

Calves are typically raised with their mother until they reach 200 to 250 kg. After this, they are transferred to a fattening farm where they are fed concentrate and straw until they reach 400 to 580 kg body weight. Final slaughter weight is dependent on the breed, sex, and consumption purpose.

Practices of feeding and health management are similar to those outlined for dairy cattle in Section 2.4. Veterinary inspections are typically carried out by local veterinary authorities at all stages of production including on-farm and at the slaughterhouse, including sanitary conditions, animal welfare, control of infectious diseases, monitoring for bovine tuberculosis, bovine brucellosis and enzootic bovine leucosis, ante-mortem examination, and post-mortem testing for bovine spongiform encephalopathy (for animals over a certain age) (*e.g.* EU, 1964; EU, 2001b).

For beef cattle in EU member states, traceability and documentation requirements apply, similar to those for dairy cattle as described in Section 2.4 (EU, 2004b).

2.6. Cultured fish

For fish production through aquaculture, a number of different production systems exist (extensive, semi-intensive, or intensive) and production can take place in natural settings, tanks, fresh water and/or seawater (EC, 2012a). In addition, some producers are involved in the full production cycle whereas other specialise in a specific stage of development such as breeding or fattening.

Diets for fish feeding are predominantly industry-manufactured and come in the form of granules or pellets, for which the specific contents of ingredients are based on the species and nutritional requirements for the different production stages. As many farmed fish species are carnivorous, high protein content is required for diets. Fishmeal and fish oil are commonly used in feeds as the principal protein and energy source and are mainly obtained from wild catches. In addition, shrimp, ground nut, maize, soya, and rice flour can also be used to provide protein. These protein sources are combined with other ingredients such as vegetable proteins, cereals, vitamins, and minerals.

Fish feed can be either complete or supplemental. Complete feeds supply all ingredients needed for growth and maintenance and are provided in intensive systems that involve high stocking densities. Supplemental feeds are provided to support natural food (insects, algae, plankton) available in ponds or water sources and help fortify the diet with extra protein, carbohydrate, and/or lipids. Feeding frequency and amounts are species and production stage dependent. In general, larvae and small fish require high protein levels and frequent feeding. As fish grow, rate of feeding as well as protein levels generally can be decreased. With regard to aquaculture of seafood-producing species such as finfish and molluscs, the EU has traceability requirements in place for farmed fish (EU, 2006). This is also done with a view on prevention of the spread of infectious diseases among farms. Business operators are thus required to keep records of all movements of animals in and out of the farm or mussel-growing area, whilst also keeping records of disease or mortality incidences within the same epidemiological unit. Record-keeping requirements are also imposed on processors and transporters, whilst Member state authorities shall ensure that processors keep records of animals and products entering and leaving their compounds, and that transporters document establishments visited, mortalities that occurred during transport and any exchange of water that took place en-route.

For health inspection and controls of farmed fish species, EU legislation stipulates that each member state should put in place a risk-based health surveillance scheme, including provisions for the issuance of health certificates and movements between areas of a given health status (EU, 2006). High-, medium-, and low-risk farms are distinguished, taking into account the risk of spread, farming conditions, and the sales of live aquatic species. Also distinguished are active and targeted surveillance, the first differing from the latter in *e.g.* on-farm examination of the animal population and diagnostic samples to be taken on suspicion of a disease instead of a prescribed sample (EU, 2006).

2.7. Conclusions

Within the various production systems for different livestock species (bovine, porcine, avian, piscine), animals are traceable, either at the individual level (bovine, porcine) or at the herd level (avian, piscine), in line with the requirements set out in EU legislation. This is likely to have its implications for the statistical power of the monitoring schemes, namely whether the statistical unit is a group or an individual, hence also the possibility to discern diverging trends in health data from the baseline. Notwithstanding all biological differences between the livestock species it appears that particularly greater holdings do have similar practices with regard to documentation and health management.

3. FEED PRODUCTION CHAIN CHARACTERISTICS AND THE POSSIBILITY TO DETERMINE THE PRESENCE OF SPECIFIC INGREDIENTS IN LIVESTOCK FEED

Whilst the previous section explored the possibility to monitor for livestock health and the traceability of individual or groups of animals, the question arises if the animals' exposure to feed ingredients derived from a specific GM product can also be determined. This would then ideally allow for the establishment of cause-effect relationships if, for example, animal health data showed trends diverging from the baseline during post-market monitoring. This also raises questions regarding the traceability of such specific ingredients as well as to the availability of data on their presence from e.g. feed inspections.

For animal feed production within the EU, regulations regarding labelling, tracing, and feed controls are in place at the EU level and transposed into national legislation by its member states. An overview of the composition and origin of animal feed in the EU is given and a specific example of the composition of diets for cattle, pigs, and poultry in the Netherlands is provided. A description of maize production in Catalonia, Spain based on interviews with farmers and producers is also provided to illustrate a working example of feed production (specifically maize production) in an EU member state.

3.1. Labelling, traceability and inspections

The feed manufacturer who first brings a feed into circulation in the EU or under whose name the feed is marketed is responsible for proper labelling. Besides the generally applicable rules for the labelling and marketing of feed, including the declaration of the feed materials present as ingredients and additives (e.g., cereal grains, forage, oil and legume seeds, by-products), similar provisions also apply to, for example, the presence of

GM ingredients and to the labelling of feeds as being organic (EU, 2003a; EU, 2007b; EU, 2009c).

Under EU legislation, feed must be traceable from the source of production to the retailer as per the requirements set out in the General Food Law [Regulation (EC) No 178/2002 (EU, 2002a)]. The responsibility for traceability lies with the feed companies, so that each company must document where and from whom feed was received, the direct purchaser of their products/goods, as well as information regarding storage and transport of goods. Written records are required to be kept for five years and should include the address of supplier, type, amount and batch of feed as well as production dates (EU, 2007b).

The European Rapid Alert System for Food and Feed (RASFF) supports a rapid and coordinated exchange of information among feed control authorities when a risk in food or feed is identified. If a member identifies a risk, it is notified to the European Commission, which then transmits the information so that corrective action can be taken. Unauthorised genetically modified organisms (GMOs) thus reported through RASFF, for example, can be registered and searched for in the RASFF web portal (EC, 2017c).

With regard to feed inspection and controls for the purpose of EU feed law enforcement, member states have to establish their own Multi-annual National Control Plan (MANCP) to ensure compliance with legislation on feed, food, animal health and welfare, as well as plant health. Member states have to report results yearly to the EC, as well as designate competent authorities to perform the official controls. The competent authority may delegate certain control tasks to non-governmental bodies, provided that these bodies meet specified conditions outlined in legislation (EU, 2004a).

Controls can take place at any point before or after release for free circulation. Member states must ensure that one or more national reference laboratories have been established for feed controls, which are supported by Community Reference Laboratories established at the EU level. Official controls, which are carried out by the competent authorities of the individual states, take place at all stages of the animal feed production chain. This includes farms, feed mills, mixing plants, warehouses, border inspection points, manufacturers, and retailers. Individual feed materials, feed additives, premixes, and compound feed can be tested. Checks, which are carried out at random, have the main goal of ensuring compliance with current legislation regarding undesirable and prohibited substances, residues of veterinary drugs, and labelling of feed. They include verification of appropriate documentation as well as collection of samples. From 2012 to 2016, guidelines for the control of animal feed in Germany suggest that the distribution of controls in the feed sector should be divided so that 50 to 60% of controls are carried out on feed manufacturers, 25 to 35% on owners of animals, and 15 to 25% for trade (border entry points, transporters, warehouses). However, it is ultimately up to the individual states how they divide up controls (BMELV, 2012).

For feeds imported into the EU, a list of designated, authorised points of entry for different feed types has been established and is maintained under harmonised EU rules on official import controls for feed of both animal and non-animal origin from third countries (EU, 2004a; EU, 2009a). Feed must be registered with the appropriate authority no later than one business day prior to the arrival of feed at the designated point of entry. All imports are subject to documentary checks (*e.g.*, Common Entry Document) and a variable percentage is subject to physical checks, including sampling and laboratory analysis. Published yearly results for border control checks are available on the European Commission's website.

In conclusion, EU legislation has enabled the establishment of tightly controlled feed production chains in which both producers themselves as well as national member state authorities are responsible for checking the quality and safety of feed products in general, including the presence of GM ingredients in feed. The latter may be part on of national multiannual control programs, for example, which member states are required to establish for longer periods. Yet it is also obvious that such inspections and controls for GM ingredients are limited in number and therefore the outcomes of such activities may not allow for traceability and details on the presence of GM ingredients in each and every lot.

4. AVAILABILITY OF DATA ON CONSUMPTION OF FEED MATERIALS AND OF GM INGREDIENTS THEREIN

Livestock consume approximately 477 M tonnes of feed each year in the EU. From this, 233 M tonnes consist of roughages grown and used on the farms of origin. The remaining 244 M tonnes includes cereals grown and used on farms of origin (51 M tonnes) as well as feed purchased by producers (*i.e.*, compound feed) to supplement their own feed (FEFAC, 2016). In 2015, 154 M tonnes of compound feed were produced by the EU, mainly for cattle, pigs and poultry, respectively (FEFAC, 2016). The use and import of feed materials for the production of these 154 million tonnes of compound feed is summarised below in Table 1 on the basis of data from the European Feed Manufacturers' Federation (FEFAC). No distinction is made between GM and non-GM ingredients, which can be accounted for by the fact that this feature is neither comprehensively monitored for nor included in the reported statistics. Results indicate that 43 M tonnes of feed materials were imported from outside the EU in 2015, representing approximately 28% of the total use of feed materials in compound feed in the EU-28, predominantly cereal grains, oil seed cake and meal, and co-products from the food and bio-ethanol industry (FEFAC, 2016). It is important to note that these data neither allow for linking of these feed materials to their original plant origin nor do they contain any information on the possible presence of GM products. Production data regarding compound feeds for relevant animal categories can be obtained from the FEFAC and a list of approved feed establishments by member state can be obtained on the European Commission website. Volume and origin of these imported feed materials can be derived from the Eurostat database on international trade and is based on import and export data provided by statistical bodies of the member states. However, the classification and names according to the common nomenclature (CN) as used in the Eurostat database is substantially different from the classification in the European feed catalogue (EU, 2013a), which provides an EU-wide agreement on the use of names and descriptions of a large number of both unprocessed and processed feed materials and technological processes that may have been involved. Individual feed ingredients need to be linked to the classification of (groups) of ingredients in Eurostat.

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4.1. Feed materials used in Dutch livestock husbandry

The Netherlands were used as illustrative example given the quality of data available and also its role as a major importer and exporter of animal feed products, mainly because large amounts of feed materials are transferred via the Netherlands, e.g., the seaport of Rotterdam, to or from other EU countries.

As regards the types of diets provided to the different livestock species considered, poultry diets for broilers and laying hens in the Netherlands are largely composed of compound feeds. In addition, wheat is supplied to a large number of poultry farms for inclusion in broiler diets. Pig diets in the Netherlands are largely composed of compound feeds and moist by-products. In addition, a limited amount of dry single ingredients, *e.g.*, wheat and soya bean meal, is directly supplied to pig farmers for inclusion in the ration. In general, pigs do not receive any roughage unless kept in organic systems. Cattle diets generally involve roughage (mainly fresh grass, grass silage and corn silage) and concentrates. Overall, the amount of roughage imported from outside the EU is negligible. Grass is typically grown on-farm or in neighbouring areas. The same is true for maize silage, although some maize silage may be traded with other EU member states, especially from neighbouring countries (Belgium, France, and Germany) (Boerenbusiness, 2013).

The majority of concentrate is supplied as compound feed by the compound feed industry. In addition, moist co-products from the food industry and some single dry ingredients, *e.g.*, soybean meal, are supplied to dairy farms for on-farm inclusion in feed rations. Based on Dutch national data for feed consumption, approximately 23% of the ration is from compound feed and 5% from moist co-products (Table 2).

No published information is available on the composition of compound feeds for different animal categories involved in commercial animal production and the distribution of feed materials among animal categories. This information is generally regarded as the confidential knowledge of feed companies. Therefore, in this study linear programming was used to estimate diets for a wide range of livestock species using the price and availability of feed materials in 2011 and nutrient standards for respective diets (CVB, 2010). The resulting diet composition was discussed with experts from several feed companies to assure that these diets reflected the composition of compound feeds as used in practice. Subsequently, we aggregated the results to mean diets for pigs, poultry and cattle (ruminants) based on the relative amount of feed per animal category (Bikker et al., 2010). Based on the results (summarised in Table 2), we also calculated the distribution of feed materials among the different groups of animals. The results indicate that intact cereal grains were largely used in pig and poultry diets, whereas co-products of cereal grains, *e.g.*, wheat middling and maize gluten feed were largely used in pig and cattle diets. Soybean meal was largely used in poultry diets, palm kernel expeller in ruminant diets, and rapeseed meal in pig diets.

Since most of the GM crops are grown in non-EU countries, it is particularly relevant to use statistical data to gain insight into imports of feed materials from outside the EU. In most of the important countries of origin for selected feed materials outside the EU (Table 2), GM crop cultivation is performed on a large scale, including GM varieties of various of the crop species mentioned (e.g., maize, cotton, oilseed rape, soybean, sugar beet, etc.).

Besides the various dry products featured in Table 1, also moist products are used as feed ingredients, particularly moist co-products from the food and beverage industry, which are used in diets for cattle and pigs. The majority of moist co-products is derived from cereal grains (wheat, barley, maize), potato and sugar beet pulp. Because of their high moisture content and high transport costs, these products are mostly locally produced or imported from neighbouring countries within the EU such as Germany, Belgium and France and hence likely to be from GMO-free ingredients. In general, factories for the processing of cereal grains and sugar beet pulp are located in regions with high production of these crops. However, it cannot be excluded that the factories involved in the primary processing of cereals and other plant products also make use of imported raw materials. Additionally, processing of soybeans is fully based on imports from Brazil, Canada, Paraguay, or the USA, which are countries that do cultivate GM crops.

<<<< Place Table 2 around here >>>>

According to our knowledge, there is no comprehensive, publically available data source that allows for precise determination of the amount of GM vs. non-GM feed material imported into, traded within, as well as used within the EU. In addition, there is limited information available on the allocation of feed materials to different animal categories, and, no typical composition of major compound feeds representative for the EU has been established that would enable estimation of the use of feed materials for cattle, pigs, and poultry. Differences between rations and feeds among the different EU countries also make it difficult to use an average composition representative for all countries

To gain insight from a member-state level regarding the use of GM vs. non-GM feed, each country would need to provide estimates of the percentage of feed material used and imported by major crop category (*e.g.*, maize, soybean) and base GM percentage on approximations of the cultivation of GM vs. non-GM crops in the exporting countries of origin. In addition, to determine use by livestock category, each country would need to compose representative national diets for major livestock categories trying to gain a rough understanding of the possible use and distribution of GM vs. non-GM feed materials by major livestock category. We recommend that each country compose representative national diets for the major livestock categories in order to determine the distribution of feed ingredients between animal species..

4.2. GM feed authorizations in the EU

Currently, there are 100 GM crops approved for feed and food use in the EU and one crop approved for cultivation in the EU. These approved crops include 68 GM variants of maize, 15 of soya bean, 12 of cotton, 4 varieties of oilseed rape, and 1 variety of sugar beet. The single crop approved for cultivation is MON 810 maize (EC, 2017e).

4.3. GMO production

The International Service for the Acquisition of Agri-biotech Applications (ISAAA) publishes yearly overviews of GM crop production worldwide. From the 2016 report (James, 2016), it can be seen that production of the four major GM crops (soy, maize, cotton and canola) as well as other GM crops has largely been steadily increasing. However, the number of commercially grown GM crops is still relatively small in comparison to the total number of crops produced globally. In 2016, the USA was still by far the largest producer of GM crops worldwide, accounting for 39% of the global acreage. Brazil (27%) and Argentina (13%) are the next major GM crop producers, followed by Canada (6%) and India (6%), all four with more than 10 million hectares annually planted to such crops. Paraguay, Pakistan, China, South Africa, Uruguay, Bolivia, Australia, the Philippines, and Myanmar are also substantial producers, whilst each of these countries produced less than 4% of the total area of GM crops in 2016. With regard to the EU, the only crop approved for cultivation in 2016 was insect-resistant maize. Within the EU, Spain is a major producer of GM crops and was ranked 15th worldwide in terms of production area in 2016. Therefore, Spain will serve as an example below for GM maize production within the EU. Portugal, the Czech Republic, and Slovakia also play a role in EU GM crop production; however, their contribution is relatively small at less than 50,000 hectares of GMO production per country (James, 2016).

4.4. EU Regulations

Legislation of GMOs in the EU encompasses various regulations covering different aspects of their application, such as GM food and feed, as well as field cultivation, import and processing of GM plants (EU, 2001a; EU, 2003a). Complementary aspects covered by parallel regulations include, for example, the international movement of GMOs, post-market environmental monitoring, and also guidance on the safety data to be provided with dossiers on GM plants (EU, 2013b). In 2010, the EU issued new recommendations regarding safeguard and co-existence measures for GMO cultivation, as part of a Directive which allowed member states to restrict or prohibit cultivation of GMOs on their territories (EU, 2015). Under this so-called "opt-out" procedure, a member state can request a restriction of the geographical scope of the approval if it were to be granted, so that its territory is excluded. After authorization, it can also invoke the opt-out procedure based on compelling grounds related to non-scientific, non-risk issues such as public policy.

Insect-resistant MON 810 maize was authorised in 1998 and is cultivated for commercial purposes (EC, 2015). The other abovementioned approvals are not for cultivation of the particular GM in Europe but for, for example, import and processing, and use as food and feed.

Presently, it is estimated that over 90% of feed materials are labelled as containing GMOs or GMO-derived materials. The European requirements for the labelling of GMOs are detailed in Regulation (EC) No 1829/2003 (EU, 2003a). All products need to be labelled if they contain or consist of GMOs, or if they are produced from or contain ingredients produced from GMOs. The threshold for labelling is 0.9% for each crop that is used to produce the final product, provided that this presence is adventitious or technically unavoidable. For example, if different soy ingredients are used in a particular feed material, the overall percentage of GM soy is calculated and this total percentage of GM soy should not exceed the limit of 0.9%. Assumed that the presence of trace amounts of GMOs should be adventitious, importers and producers need to take measures to segregate non-GM from GM material. Dilution of the GMO component to below the set threshold is illegal. In this case, such a product would still need to be labelled. Every GMO with an EU market authorisation is assigned a unique identification code consisting of numbers and letters. This code is included in all documents that accompany the product throughout all stages of the production and distribution chain, enabling tracing back to the origin.

4.5. Non-approved GMOs

Regulation (EC) No 619/2011 formulates additional measures, including methods of sampling and analysis, for the monitoring of feed, not food, with relation to the potential presence of GMOs or derived materials that have already obtained a positive scientific evaluation by the EU but are not yet approved. GMOs for which the period of approval has expired are also included (EU, 2011b). The technical implementation of the zero threshold for unapproved GMOs is set at the 0.1% level, the lowest level of GM material considered by the EU Reference Laboratory for the validation of quantitative methods. If levels of unapproved GMOs exceed this threshold, the particular feed batch involved may not enter the European market.

4.6. Traceability

Rules regarding the traceability of GMOs are outlined in Regulation (EC) No 1830/2003 (EU, 2003b) and apply to products consisting of, or containing, GMOs, and food and feed produced from GMOs, but not to medicinal products for human or veterinary use. Member states are obliged to set up monitoring programmes including sampling and analysis, to maintain GMO traceability regulations. Traceability regulations for GMOs should facilitate both the withdrawal of products where unforeseen adverse effects on human or animal health or the environment have been observed, as well as the targeting of monitoring to examine potential effects on the environment. Traceability should also, in specific cases, facilitate the implementation of risk management measures in accordance with the precautionary principle.

Traceability requirements for food and feed produced from GMOs should be established to ensure that accurate information is available to producers and consumers as a means to ensure freedom of choice as well as to enable the control and verification of labelling claims. Information with relation to the presence of GMOs should be transferred from importers/producers to each subsequent step in the food and feed supply and production chains.

Importers or producers need to establish whether a product contains or consists of GMOs, and, in the case of viable organisms, which GMOs are involved. At all subsequent stages of the food and feed supply and production chains, this information needs to be transmitted to the next step in the supply and production chains. Producers will need to have systems and procedures in place to make the relevant information traceable for a period of five years from each transaction.

4.7. Feed inspection and control (GMOs)

According to EU regulations, all countries/member states are required to set up a monitoring system to enforce that GMO labelling and traceability requirements of Regulation (EC) No 1830/2003 (EU, 2003b) are met. The European Food and Veterinary Office regularly audits all Member states; these audits include checks on national monitoring programs as well as compliance with GMO regulations. Summaries of findings are published by the Food and Veterinary Office in their audit reports and can be accessed online. From recent key findings provided by several member states regarding GMO monitoring, it can be concluded that only a limited percentage of feed is tested for GMOs within the EU. However, it seems that the majority of feed materials are correctly labelled with no indications of the presence of non-authorised GMOs.

4.8. Maize Production in Spain, A working example

Spain grows the largest amount of GM maize (MON 810) in the EU and the percentage of GM maize produced has steadily increased over the past decade. The distribution of GM maize production is not homogeneous throughout Spain. High-producing regions such as Aragón (71% of cultivated maize was GM in 2016) and Catalonia (59%) are located in the northern part of the country. Within Catalonia, most GM maize is grown in the region of Lleida and l'Empordà (59% and 64%, respectively, in 2016); it is also important to note that only 0.1-0.15% of cultivated maize is organic (MAGRAMA, 2015).

4.8.1. Coexistence of GM and non-GM Maize in Spain

Spain does not have yet an official regulation regarding coexistence of GM, conventional, and organic maize. However, the National Association of Plant Breeders [Asociación Nacional de Obtentores Vegetales] publishes guidelines detailing practices for farmers cultivating GM maize every season (ANOVE, 2016). Recommendations include the use of buffer zones between GM and non-GM crops as well as sowing GM and non-GM crops at different times to reduce the risk of cross-pollination. In addition, farms involving organic maize production are recommended to be physically separated from areas cultivating GM crops.

Farmers are obliged to present a signed declaration [DUN, Declaració Unica Agrària], regarding their cultures to the competent authorities each growing season. The declaration must include the seed variety used, the area cultivated, yield and, since 2013, place of commercialisation.

The GM and conventional maize production in Catalonia is selected as example to illustrate the organisation of a typical maize production chain from harvesting to feed manufacture. Catalonia requires approximately 2,100,000 tonnes of maize per year, the majority of which (80.8%), is used for animal feed. It is important to note that Catalonia produces only 25% of its maize requirements.

After harvesting, grains are dried (humidity approx. 11%) in local drying facilities. There is a register of entries and issues that contains information regarding the variety of maize, where the maize was grown, weight of the batch, and humidity levels. Since the vast majority of locally produced maize is for feed purposes and transgenic and conventional maize are purchased for the same price, care is not taken at dryer facilities to separate transgenic and conventional grains. Therefore, the maize production is typically labelled as GM.

For transportation of maize grain and feedstuffs documentations are required based on the Convention on the Contract for the International Carriage of Goods by Road and must include name and address of the sender, carrier, and receiver, date, vehicle specification, the type of load, weight of the load, origin of the load, destination of the load. In addition, feed composition (including whether it is GM or non-GM), nutritional composition, lot number, weight. The identification details of the feed manufacturer must also be documented.

A range of different feed manufacturers, from small agricultural cooperatives to large companies, exists in Catalonia. However, feed manufacturers import a significant amount of maize mostly from France, besides Bulgaria, Brazil, Ukraine, and the USA. Imports occur through the ports in Tarragona and Barcelona and each batch must be accompanied by documentation with the same details as described above for vehicle transport. Upon entry, all information related to delivery notes and transport is registered for the feed manufacture. Additionally, quality control of every batch is carried out according to regulations (EU, 2002c).

4.9. Conclusions

From the data reviewed, it becomes apparent that, in each and every situation, not all feed that an animal has been exposed to will be traceable back to the farm of origin, nor would it be possible to determine the proportion and identity of the GM-crop-derived ingredients ingested based on available data. The latter could include feed production and trade statistics, monitoring data, and records kept by chain actors. The presence of GM ingredients can be measured specifically using DNA-based detection techniques, yet this is done to a limited extent in practice. The example of coexistence in Spain, where GM maize is cultivated, shows that data on the specific GM product present in feed is rapidly lost downstream in the subsequent stages of mixing and processing feed ingredients from various sources.

5. Livestock husbandry systems using non-GM feeds

Two categories of commercial practice that explicitly require livestock operations to feed their animals diets containing non-GM feed ingredients are highlighted here. The question was raised as to whether these livestock operations could serve as a comparator for animal production chains where GM feeds are allowed to be used, so as to be able to discern possible impacts of the latter on livestock health.

5.1. Organic farming

Organic farming was considered in more detail as its principles preclude the use of GM feed ingredients, among others.

In 2013, approximately 1.7% (185,000) of agricultural holdings within the EU-28 were estimated to be involved in organic agriculture. The majority of these holdings (81%) were within the EU-15, particularly Italy, Austria, Spain, Germany, Greece, and France (EC, 2016).

5.1.1. Regulations on organic agriculture

Three main regulations cover different aspects of organic production in the EU, including:

- Organic production, distribution, trade, and labelling (EU, 2007b),
- Organic animal and plant production (EU, 2008b), and
- Import of organic products from third countries (EU, 2008c).

Regulation EC (No) 889/2008 sets out control measure requirements for organic products (EU, 2008b). Member states should designate the competent authorities and/or approved private inspection bodies responsible for performing the official controls and certification for organic production. When controls are carried out, the operator should have information, among others, on practical measures taken to ensure compliance with the organic production rules, as well as precautionary measures to reduce the risk of contamination by unauthorised products. Every member state must also provide annual results (number of organic producers, importers, exporters, organic crop production, areas under conversion, organic livestock numbers) to the European Commission (EC, 2017d).

Organic feed must be produced from organic materials except where feed material is not available on the market in organic form, in which case they may be sourced from operations in the course of conversion to organic agriculture. The use of growth promoters, synthetic amino acids, and GMOs is prohibited, however, less than 0.9% of adventitious GM material is allowed if it entered the product unintentionally.

During transport, organically-produced feed, in-conversion feed, and non-organic feed should be physically separated. Operators should ensure that organic products are transported to other units in appropriate packaging, containers or vehicles and closed in such a manner that substitution of content cannot be achieved without manipulation or damage of the seal. A record of all the transportation processes should be kept. Also for the storage of products, areas should be managed in such a way as to ensure identification of lots and to avoid any mixing with or contamination by non-organic products and/or substances. When processing of organic and non-organic products occurs in the same place, adequate measures should be taken to avoid cross-contamination. Operators should establish protocols to avoid contamination with unauthorised substances and avoid the labelling of non-organic products with organic labels.

5.1.2. Organic livestock

Organic livestock production has developed faster for ruminants than pigs and poultry as ruminants can be fed on grassland and roughage, in contrast to pigs and poultry, which require grain and protein-rich feed.

With regard to purchase and trade of animals, non-organic animals can be bought under certain conditions, such as a minimum period of their lifespan spent within the organic system before slaughter, whilst no more than 10% of non-organically reared female animals can be used for herd renewal. Livestock must be fed 100% organic feed. For herbivores, at least 60% of feed should come from the farm itself, or, if not feasible, be produced in cooperation with other organic farms, whilst for poultry and pigs, the minimum threshold is set at 20% (EU, 2008b; EU, 2012). Records should be kept for feed (supplements, proportion of ration ingredients, periods of access to free-range areas) as well as disease prevention and treatment (type of treatment, product, withdrawal period).

For dairy cattle, there is a range of different organic farm management and husbandry systems within Europe, whilst herd sizes and breeds vary across Europe (*e.g.* Gratzer et al., 2012). Artificial insemination is permitted and farms vary in their breeding practices. With regard to feeding, for example, at least 60% of the dry matter in the daily ration should consist of roughage, fresh or dried fodder, or silage. A reduction to 50% for a maximum period of 3 months in early lactation is allowed (EU, 2008b). Currently, yearly production data is only available for all dairy cattle (conventional plus organic) and no resource exists to allow direct comparison of organic and conventional production parameters. This, combined with the wide variety of husbandry systems and farm sizes throughout the EU, makes it difficult to compare organic and conventional dairy cattle production. However, several studies conducted in Germany comparing organic and conventional farming found no significant health and production differences apart from lower milk yields in organic dairy cattle (BÖLN, 2012; Hoerning et al., 2005; Mueller and Sauerwein, 2010).

As with organic dairy cattle, there are a large variety of beef cattle husbandry systems within the EU. With regard to health and performance of organic beef cattle, research carried out by the German Federal Program for Organic Farming between 2001 and 2011 found similar health and production outcomes in organic and conventional systems (BÖLN, 2012; Hoerning et al., 2005).

Organic pig husbandry systems in the EU can be broadly divided into three major categories: indoor housing, outdoor housing and mixed housing. In contrast to conventional systems, organic standards as laid down in EU legislation require that animals have outdoor access (EU, 2007b; EU, 2008b). Some private schemes define even stricter rules. For example, the Soil Association requires all organic pigs in UK to be kept on pasture, whilst the Swedish certifier KRAV requires access to pasture during summer for all pigs. Typical practices vary across Europe, with organic pigs being housed mainly indoors and given outdoor access via concrete runs in some countries, and outdoors all year round with natural shelter in other countries, as well as combinations of indoor and outdoor housing (FiBL, 2011). As for other livestock species, a number of studies did not find improved performance in organic production systems (Millet et al., 2005; Sundrum, 2001).

Organic poultry is kept in free-range systems with lower stocking densities than in conventional holdings. There is a large diversity of production systems throughout the EU with regard to flock and farm size. With regard to feeding, EU legislation specifies that roughage, fresh or dried fodder, or silage should be added to the daily ration (EU, 2008b).

A large number of studies have evaluated and compared performance of organic *vs.* conventional poultry. Varying results have been published, however, in a number of studies, mortality was found to be similar among organic *vs.* conventional broilers. However, difference in feed conversion ratios (lower in organic broilers) were found as well as bacterial carriage and antimicrobial resistance (higher in organic broilers) (Ferrante et al., 2008; Luangtongkum et al., 2006; Van Overbeke et al., 2005). One study surveying farms in, France, the Netherlands, and Switzerland found higher mortality and lower egg production among organic laying hens (Leenstra et al., 2012). A review paper focusing on different housing systems in laying hens concluded that organic systems for laying hens provide better welfare in terms of allowing bird to perform their natural behaviour, however, from a production standpoint, results are inconclusive regarding which production system is most favourable (Sosnowka-Czaja et al., 2010).

For organic aquaculture production, EU legislation poses specific requirements. These include, for example, separation of organic from non-organic units, maximum fish stocking densities, and prohibited use of artificial hormones to induce spawning. Organic feeds should be used and supplemented by feeds derived from sustainably managed fisheries (EU, 2009b). In 2008, there were an estimated 123 certified organic aquaculture operations within the EU, accounting for half of the world production of organic aquaculture products. Greece, France, Hungary, and Ireland are the top five EU states in terms of organic aquaculture; growth of the organic market is strong in France, Germany, and the UK (EC, 2012b). Whilst salmon accounted for more than 80% of the organically labelled fish production within Europe in 2012, this accounted for 0.7% of the total Norwegian production as compared to 69% of Irish and 1.4% of European salmon production being organic (Zubiaurre, 2013). In order to further remove obstacles to the development of organic aquaculture in Europe, the recently concluded OraQua project had formulated recommendations based on consulted stakeholders' feedback, as a basis for science-based amendments to EU legislation on organic aquaculture. Amongst others, it was recommended to increase the options for feed ingredient sourcing. A greater diversity of ingredients would thus allow to better meet the cultured fish' dietary needs for amino acids and other nutrients (OrAqua, 2016). Interestingly, similar concerns previously raised by the expert group for technical advice on organic production, which advises the European Commission, in response to which legislation had already been amended to allow fish farmers to feed whole fish and add the amino acid histidine produced from fermentation to feed (EU, 2016).

5.2. Non-GM feed

A number of countries within the EU (Austria, France, Germany, and Luxembourg) have voluntary labelling schemes for eggs, meat, or milk derived from animals that were fed with non-GM feed. In Germany for example, since 2008, it has been possible to apply the label "without genetic engineering" to animal products such as eggs, meat and milk. The German competent authorities monitor for compliance and regulations according to the German "Act on the implementation of European Community or European Union regulations in the field of genetic engineering and on labelling for foodstuffs made without genetically modified methods (EGGenTDurchfG)" (BVL, 2015), which are allow for accidental, technically unavoidable admixtures of approved GM crops, provided that they remain below the threshold of 0.9%. Moreover, animal should not be fed GM feed during a minimal period before slaughter, ranging between 6 weeks for egg production in poultry and 12 months before slaughter for cattle. In contrast to organic agriculture, vitamins, enzymes or other additives manufactured with gene technology are permitted, as is treatment with genetically engineered drugs or vaccines.

Brazil is the leading country for certified non-GMO soy production. It was estimated that in 2015, 12% of Brazilian soybean production would be free from genetic modification, corresponding to 3.7 million hectares, of which 1.3 million were certified non-GMO, out of 2.15 million hectares globally. This is followed at some distance by other countries with certified non-GM soybean production, including India, China, EU-28, USA, Canada, Russia and others, in decreasing magnitude (CERT ID, 2015). However, the quantity Europe produces is too small to cover the needs of the animal feed industry. For producers and suppliers of non-GM feed, third-party systems provide certification of their products (Pelaez et al., 2010).

Multiple resources exist with regard to availability of non-GM feed suppliers and producers. Cert ID, for example, is a global company that offers third-party certification to agriculture producers, certifies approximately 70 companies for non-GMO and EU regulatory compliance programs. It has a focus on products supplied from Brazil, the world's largest non-GM soya producer, as well as India and North America. Additionally, it has established a GMO testing laboratory that is based in Germany and provides GMO testing for a range of agricultural and feed production companies (CERT ID, 2013).

In 2016, seven out of the 10 largest German dairy companies produced "GM-free" products with 839 retail items sold in Germany labelled as GM-free. This trend is likely to continue as an increasing number of retail businesses is expanding or even limiting their dairy product range to GM-free products (VLOG, 2016). The production and feeding practices of producers surveyed varied depending on the type of farm, however, the majority fed forage comprised of maize and grass silage and purchased certified non-GM compound feed. For those that produced their own feed materials, the main protein source used was rapeseed (Deumelandt and Bronsema, 2013). A website listing providers and producers of GM-free milk products in Germany is available for public access, which currently features slightly more than 1,000 dairy products (VLOG, 2017).

In 2009, the first chicken meat labelled as GM-free chicken meat was brought onto the German market by an integrated poultry producer in Germany who sourced feed ingredients from guaranteed GM-free regions and producers in Brazil, with a traceability and inspection scheme in place (Dunn, 2009). Since then, the number of poultry products that have been granted the "GM-free" label in Germany has risen to over 1,300 products as of 2017 (VLOG, 2017). Similar examples can be provided for a range of other products from livestock, such as eggs and meat, as well as honey.

5.3. Conclusions

The prohibition of the use of GMO-derived feed ingredients in organic livestock husbandry as imposed by EU legislation, among others, makes the organic production chain a potential comparator for studies on the potential impacts of non-organic features such as GM feeds, on livestock health. It has to be taken into account that besides the absence of GM materials also other characteristics of the organic husbandry operations may differ from that of conventional ones, such as size of holdings, animal breeds, access to meadows, forage as feed ingredient, and production cycles, which may constitute confounding factors in this comparison.

6. CONCLUSIONS

Findings from this review indicate that for cattle, fish, pig, and poultry chains, EU regulations facilitate clear tracing of animals throughout the production chain. The system of identification and registration for cattle requires individual tracing of animals from birth to slaughter. For fish, pigs, and poultry, individual tracing is not possible, however, regulations are in place to enable tracing of production groups or batches.

In terms of the structure and features of livestock production systems (*e.g.*, farm sizes, veterinary oversight), considerable variations were found to exist throughout the EU, particularly for cattle, fish, and pig production chains. Additionally, availability of health and production data was found to be variable. All EU member states carry out official yearly inspections and controls, however, these controls focus primarily on compliance with documentation and identification requirements as well as infectious diseases, and do not provide information about GM feed consumption. Organic systems, due to their prohibition of the use of GM feed (less than 0.9% of adventitious GM material is allowed), offer a possible way to examine production systems that do not use GM-feed. However, similar to conventional systems, a large variation in husbandry and production practices was found, which poses a challenge for examining the influence of feed alone on animal health and production outcomes.

As for livestock, considerable variation in the structure and features of feed production systems was found to exist throughout the EU. Controls focus largely on compliance with documentation requirements, the labelling of feed, as well as the presence of undesirable and prohibited substances. A substantial amount of feed materials is traded among member states as well as imported from outside the EU, which makes tracing of feed complex. Additionally, the classification system of feed materials differs between the European feed catalogue and the Eurostat database on international trade. This complicates analysis of feed data since it is not possible to obtain information from the

Eurostat database on international trade for each feed material in the feed catalogue and trace it back to its country of origin. Further to this, there is a lack of information on the composition of typical diets for livestock within the EU-member states, making it difficult to precisely quantify the allocation of feed materials among the different livestock categories.

With regard to GMOs, current estimates are that over 90% of feed materials are labelled as containing GM materials. Despite this widespread presence of GMOs, there is a lack of comprehensive, publically accessible data that provides detailed information regarding the trade and use of GM vs. non-GMO feed materials. The example provided on maize production in Catalonia, Spain, further illustrates the challenge of gaining data regarding the presence and quantity of GM material in feed as all maize feedstuffs are labelled as GM since GM and conventional maize are not separated throughout the feed production chain. Despite these limitations and complexities, available data seems to indicate that the majority of feed materials within the EU are correctly labelled, with no indications of the presence of a high percentage of non-authorised GMOs.

In summary, key conclusions of this review include the following:

- EU regulations enable clear tracing of livestock throughout the entire production chain.
- Livestock controls and health data focus primarily on compliance with documentation and identification requirements as well as infectious diseases.
- The structure of different livestock sectors varies considerably within the EU. However, husbandry and production practices are largely similar for large scale producers (*i.e.*, large farms/holding) in the different livestock sectors (*e.g.*, cattle, pigs, poultry).
- Using publicly available data, it is not possible to precisely quantify the distribution and use of feed materials among different livestock species, or to precisely quantify the proportion of GMOs within animal feed. Only rough

estimates of the percentage of animal feed containing GM material can currently be made by combining cultivation data from countries of origin with import data from the country of destination.

- Although only a small percentage of animal feed is tested for the presence of GMOs, available data indicates the majority of feed materials are correctly labelled.
- Organic systems, due to prohibition of the use of GM feed provide a possibility to examine feed and animal production chains without the use of GM materials.

Based on these considerations, it appears doubtful as to whether linkage of health data on an individual animal or group (herd, flock) of animals could be linked to data on its consumption of a specific GMO. The latter would be desirable for establishing a cause-effect relationship. The solution to this incongruence could be to check for diverging trends in commonly measured animal health data. Once such deviations are identified, further investigations should focus on collecting sufficient evidence on what might have caused this deviation. Identified causes could be further tested for confirmation in more controlled studies, for example. This rather generically applicable approach is similar to the "syndromic surveillance" which is becoming increasingly popular in veterinary circles. A statistical tool as an aide for the design of such surveillance programs has been developed within the MARLON project and is the subject of a parallel publication (L. Vince et al., unpublished, submitted for publication in the same special issue).

ACKNOWLEDGEMENT

This study was carried out as part of the MARLON project ("Monitoring of Animals for Feed-Related Risks in the Long Term") financially supported by the 7th Framework Program of the European Community for Research, Technological Development and Demonstration Activities (FP7), Grant Agreement no. 312031.

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LISTING OF TABLES

Table 1 – Use of feed materials (1,000 tonnes) for compound feed production in the EU in 2015[a]

Feed materials	Usage	Import
Cereals	74,113	10,700
Tapioca	5	0
Co-products from food industry	17,507	–
Corn gluten feed	–	478
Dried distillers grain and solubles (DDGS)	–	633
Molasses	–	1,516
Dried sugar beet pulp	–	996
Citrus pulp	–	339
Oils and fats	2,847	-
Oilcakes and meals	43,890	25,844
Pulses	2,070	165
Animal meals	455	279[b]
Dairy products	1,142	–
Dried forage	2,366	–
Minerals, vitamins, etc.	4,821	–
Miscellaneous	5,700	1,993
Total	**154,916**	**42,943**

[a] data from FEFAC, 2016; [b] fishmeal

Table 2 – Main countries of origin outside the EU-27 for feed materials used in the Netherlands in 2011

Feed material	Country of origin	Diet inclusion rate, % [b]		
		Pigs	Poultry	Cattle
Wheat	Ukraine, Russia	15.9	24.5	0.6
Barley	Ukraine	23.0	4.3	0.3
Maize	Ukraine, Russia, Argentina, Brazil, USA	15.0	36.1	3,0
Maize co-products	USA	0.6	0.3	14.3
Soybean meal	Argentina, Brazil	7.0	12.1	8.3
Sunflower seed meal	Argentina	4.9	4.0	6.9
Palm kernel expeller	Indonesia, Malaysia	1.4	0.0	19.1
Lupins	Australia	0.0	0.0	0.0
Soybeans	Brazil, Canada, Paraguay, Uruguay, USA	0.0	4.6	0.0
Rapeseed	Ukraine	0.0	0.0	0.0
Other seeds	Argentina, Brazil, Canada, USA	0.0	0.0	0.0
Citrus pulp	Brazil, USA	0.0	0.0	8.2

Molasses, cane	India, Thailand, USA	1.5 [c]	0.1 [c]	3.1 [c]
Molasses, beet	Egypt	1.5 [c]	0.1 [c]	3.1 [c]
Copra fat	Philippines	0.0	0.0	0.0
Palm oil	Indonesia	0.9	0.0	0.2
Soybean oil	Argentina	0.2	0.8	0.0
Mixture of fats	Indonesia, USA	0.0	0.7	0.0

[a], derived from data on total import, relative dispatch within the EU, and import from outside the EU, includes major countries of origin of a large number of feed materials on the basis of CN codes extracted from the Eurostat database.

[b], data from Bikker (2010), may be subject to annual variation due to variable sourcing

[c], molasses in general (including beet and cane molassess), beet- or cane source not specified

Research highlights:

- EU regulations enable tracing of livestock in production chains focusing on animal identification and infectious diseases.
- Structures of different livestock sectors vary within the EU, but production practices are similar for large-scale producers.
- It is not possible to trace all feed in the EU back to the farm of origin, to quantify the distribution and proportion of GMOs.
- Available data indicate the majority of GM feed materials are correctly labelled.
- Organic systems and other certified GMO-free-feed employing practices prohibit the use of GM feed, providing a possibility to examine production chains without the use of GMOs.