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Feed safety in the feed supply chain

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A number of issues have weakened the public's confidence in the quality and wholesomeness of foods of animal origin. As a result farmers, nutritionists, industry and governments have been forced to pay serious attention to animal feedstuff production processes, thereby acknowledging that animal feed safety is an essential prerequisite for human food safety. Concerns about these issues have produced a number of important effects including the ban on the use of processed animal proteins, the ban on the addition of most antimicrobials to farm animals diets for growth-promotion purposes, and the implementation of feed contaminant regulations in the EU. In this context it is essential to integrate knowledge on feed safety and feed supply. Consequently, purchase of new and more economic sources of energy and protein in animal diets, which is expected to conform to adequate quality, traceability, environmental sustainability and safety standards, is an emerging issue in livestock production system.
Keywords. Feed, quality, safety, supply.

1. BACKGROUND

Feed supply and feed safety are intimately linked due to the fact that feedingstuffs origin, processing, handling and storage, as well as many other factors related to the market, can affect at different levels both quality and safety of feed. Accordingly, the aim of the paper is to address a few aspects concerning the feed supply chain and how it can affect feed safety, as presented at the 3rd Feed Safety Conference organized in collaboration to the "Feed for Health" (FA0802) Cost Action.

2. THE EUROPEAN FEED SECTOR

To sustain the European livestock production, about 500 millions tons of feedingstuffs are required each year within the EU-27 (FEFAC, 2008). Approximately 50% of this volume are roughages produced on-farm, 10% are grains produced on-farm, 10% are purchased feed materials and 30% are industrial compound feeds. The EU-27 produces 151 million tons of compound feed per year, which is the second largest single share of the world compound feed market (**Figure 1**) (Best, 2010; FEFAC, 2008). Most of the feed crops (75%) are produced within Europe, even though imported soybean dominates the protein supply for animal feed in the UE. The value of all feedingstuffs used by EU livestock producers, including forages produced on the farm, accounts for 36% of all inputs and 47% of the turnover in livestock production (FEFAC, 2008). Clearly, ensuring that such high volumes of traded products are conformed to adequate quality standards is a major undertaking and it is fair to say that the EU has made significant progress in defining standards and promoting legislation in this area. As a consequence the explicit and detailed formulation of the concepts of food/feed safety and food/feed quality, has given rise, within the EU, to legislation on the traceability, control and labeling of both feed and food. The result is that feedstuffs are now required to be equivalent to foods in terms of nutritional quality, technical aspects, safety

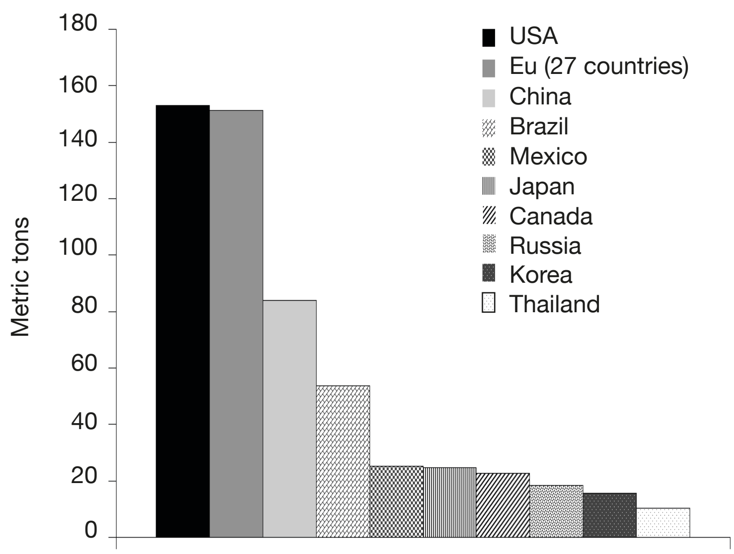

Figure 1. Main compound feed producing countries.

and so forth. These developments are based on the recognition that: wholesome feed is essential not only for preventing malnutrition, but also for promoting growth and production, and for producing a high quality food product (Pinotti et al., 2005). This implies that all aspects of food production and of the feed supply chain must be considered to ensure the safety of human food. Ensuring that feed traded in the EU conforms to quality and traceability standards is a major task. Better knowledge of the main routes of feed imported into Europe, identification of the major feed suppliers, and monitoring of final livestock destinations is important not only for ensuring feed quality but also for providing information to the consumer so that the consumer could make informed buying choices. It will be also necessary to develop and validate analytical methods (including rapid methods) to identify disparate ingredients in processed feeds in order to ensure correct labelling and conformity to quality standards. An important corollary of these developments is feed safety, which is intended not only in terms of presence of specific contaminants in feed ingredients [such as mycotoxins, plant-produced toxins and residues, as well as heavy metals and other harmful biological agents (particularly pathogenic bacteria)], but also in terms of presence of plant secondary metabolites that can affect animal health and performance.

In the case of mycotoxins contamination, the latest surveys (Taylor-Pickard, 2009) confirm that feedstuffs are typically contaminated with more than one toxin, which may have a cumulative effect in terms of toxicity in the animals. This means that if only one toxin is measured in the feed sample, even though it may be below what is considered a dangerous level on its own, when other toxins are present the combined toxicity may easily exceed safe levels (Taylor-Pickard, 2009). The risks of contamination are greater when raw materials are not traceable or derive from countries where adequate monitoring infrastructures are not in place (Pinotti et al., 2005; Cheli et al., 2008). In this field the geographic origin of feed material is also important. Although it is known that mycotoxins are ubiquitous, and not just limited to humid and hot countries, where the climate is more favourable to microbial and fungal contamination, it has been reported that some toxins can occur more frequently than other according to the producing area of the feed material. Thus zeralenone, fumonisin and aflatoxin were the most widespread toxins found in feed material (seeds meals, grain by-products, complete feeds) sampled in Asian commodities. By contrast, zeralenone and deoxynivalenol (DON) were the most prevalent toxins in continental Europe samples, even after adjusting for the seasonality of contamination for these different toxins (Taylor-Pickard, 2009). In both areas by-products typically contained higher levels of toxins contamination compared to whole raw material. These imply that multiple mycotoxin methods are required to characterize the disparate feed ingredients as well to assess their effects on cell processes and gene expression in livestock animals (Cheli et al., 2008).

Plant secondary substances, also called anti-nutritional factors, are compounds that when present in the diet may have an adverse effect on animal health and in turn on animal performance. Cereal grain non-starch-polysaccharides (NSPs) present in high amount in barley, wheat, oats and rice, are an example in this field. NSPs that include endosperm cell wall constituents such as cellulose, arabinoxylans and beta-glucans, which (according to their solubility) interfere with the digestion of starch and other endosperm grain constituents, increase viscosity in the intestine. Because they are not readily digested in the small intestine, the soluble NSPs provide a growth medium for bacterial pathogens in the large intestine and there indirect evidence that this can promote disease like swine dysentery (Lallès et al., 2007). In many case, adverse effect can be limited to acceptable levels by restricting the amount of these problematic ingredients in animal's diet. Therefore, substitution and use of cereal grains in the diet of monogastric animals, need specific evaluation beyond basic aspects such as market supply and availability. Furthermore, in order to prevent feed contamination and promote safety use of different feed ingredients, above toxins monitoring and accurate feed formulation, nutritional interventions that can improve feed efficiency and modulate the immune system and gut microflora should be also considered in practice. Thus, inclusion of feed additives such as antioxidants (Baldi et al., 2004; 2006; Adamans, 2006), mycotoxins binders (Jacela et al., 2010; Whitlow et al., 2010), probiotics (Choct, 2009) and specific feed enzymes (Bedford et al., 2001), to solve problem present in the feed may be required in certain situations.

3. FEED FOOD FUEL: IMPLICATION FOR FEED SUPPLY AND FEED SAFETY

The nature of livestock production is also changing rapidly in many emerging economies, as well as in developed countries. The entire European food supply chain, from plant breeding, feed crop production and feed formulation, to the production of meat, dairy products, eggs, and aquaculture products, is experiencing challenges created by competition from low production cost countries and restrictions imposed by national and EU regulations on environmental impact, animal welfare and traceability. A further emerging aspect is the competition between different agriculture raw material-producing sectors. For example, food, feed and fuel demand have accelerated the trend demand growth for agriculture commodities

(Currie, 2007). However, since agricultural production serves food, feed, industrial and also renewable energy use, any change in competitiveness of any of these three main outlets, leads to competition for arable land. This situation is also clear in the few key outlooks (Dell'Orto, 2009) reported below:

- feed: use of maize as feed is projected to rise from 625 to 964 million tons from 2002 to 2030;
- food: world milk and meat consumption will increase by 11% and 18% from 2002 to 2030;
- fuel: US corn use for ethanol production has doubled in the last few years (in 2012, 30% of US corn production will be used in ethanol); European biodiesel outlook is much stronger than the US ethanol outlook.

These considerations suggest that above the competition between sectors for raw materials and the availability of by-products from biofuel plants, such as distillers grains and crude glycerin for use in feed, is likely to increase in the near future. This scenario will be able to generate new trends in the feed sector and in the feed supply chain, as recently presented by de Paz Sanchez (2009). In fact, by-products use and combination in animal diets formulation are matter of research worldwide. Thus de Paz Sanchez showed in 2009 that it is possible to substitute partially "classic" source of energy and protein in dairy cows diets by using a balanced by-products combination. This substitution reduced feed cost by 9% (compared to traditional ingredients). However, above economics and marketing issues (**Table 1**), further aspects that have to be considered in including these products in food producing animal diets, are their nutritional and safety facts and effects, as reported below.

As reported by Lemenager et al. (2006) the challenges associated with adding these types of by-products to animal feeds can be divided into four main areas:

- variation in nutrient content and nutrient availability between batches (within and between plants);
- effects on animal performance, end-product quality, and nutrient management;
- by-product handling, storage, and processing in feed plants (also called technological quality);
- farmers and producers education.

Much of the variation in nutrient content [*e.g.*, corn distillers grains: crude fiber (5-14% on dry matter basis) and crude fats (3-12% on dry matter basis)], digestibility, and availability is related to the production process itself (*e.g.*, drying, amount of solubles added, clean system) of these by-products (Lemenager et al., 2006). In the biofuel production the glycerol obtained from the trans-esterification process is separated from the biodiesel by gravity (Zigger, 2008). The concentration of this glycerol is only about wt-50% and it is often referred to as raw glycerol. This raw product contains several ingredients (alcohol, base catalyst, soap, etc.) that need to be cleaned and removed. These processes result in crude glycerol products with 80-85% purity, which can be used in animal feed. Glycerin from biodiesel production has been investigated at different levels of inclusion (up to 10% of the dry matter) as a pure energy source in poultry and pig diets formulated to meet typical feeding standards. Results obtained indicated that glycerin can be a useful energy source in non-ruminants diets. However, safe levels of the residual methanol (resulting from separation of the fatty acids in biodiesel production) and free fatty acids in crude glycerin remain to be determined (Zigger, 2008).

In the case of the dry corn distillers' grains (DDGS), salt (sodium chloride) is used as the drying agent, and sulfuric acid (sulfur) is added during the processing to adjust pH (Lemenager et al., 2006). Each of them can create nutritional challenges when included in animal diets. In particular high inclusion rate of DDGS in beef cattle diets can increase sulfur intake above the tolerable

Table 1. Non traditional ingredients features (de Paz Sanchez, 2009).

Features	Effects
Advantages	Formula cost reduction
	Reduced ingredient market speculation
	Increased competitivity
Disadvantages	Marketing effort to support the new ingredient
	Reduced turnover of ingredients. Poorer conservation
	Need for more storage silos in the feed mill
	Tag of feeds contains the feed formula, so customer is fully aware of raw material inclusion in the feed

level of 0.4% of the diets (NRC, 1996). This has been also reported recently by Drouillard et al. (2009), who evidenced how a chronic exposure to high levels of dietary sulfur, induced by an elevated inclusion rate of distiller grains (30% of the dry matter intake) in the beef diets, can alter feed consumption (reduced), ruminal fermentation, fermentative end-products, and cattle performance.

When processing properties of DDGS are considered, flowability in the feed plant is a key handling feature. Factors affecting flowability of distillers grains include product moisture and fat content, shape of particles, particles size distribution, bulk density and, indirectly, DDGS compaction tendency (Klein-Hessling, 2007; Shurson et al., 2008). These factors can be improved by appropriate processing (*i.e.* cooling after drying, particles shape and size specification) of DDGS at the production. Another concern is pellet quality. Pelleting is a process that eliminates bridging problems for diets with small particle sizes, decreases dustiness and segregation of ingredients, increases bulk density, and improves palatability. Pelleting of feeds containing DDGS levels above 5-7% can affect pellets and pelleting by reducing the pellet throughput, pellet durability, and feed efficiency potential. For example, it is reported that fine-grinding of a feed ingredient [corn is finely ground (< 400 microns) to improve ethanol yield/bushel of corn – one ton of corn is equivalent to 39.37 bushels – Lemenager et al., 2006] in combination with the resulting bad pellet quality can contribute to gastric ulcers in swine (Wondra et al., 1995; Melnichouk, 2002; Lemenager et al., 2006). In this context, however, the remaining ingredients base in the compound feed formula can prevent/correct some of these effects. For instance, high wheat based diets commonly found in Western Europe would likely absorb 10% DDGS without any major impact on pellet quality (Klein-Hessling, 2007).

These considerations indicate that the farmers, nutritionists, feed technologists and others, would need to be trained about not only the nutritional quality of these products, but also about their technical aspects and safety. Consequentially, the science-based information concerning how to use efficiently, effectively, and profitably these by-products in livestock rations, are needed.

4. FEED SUPPLY AND FEED SAFETY IN AQUACULTURE

Aquaculture production of seafood will probably remain the most rapidly increasing food production system worldwide through 2025 (Koeleman, 2009). This implies that feed supply and availability of raw materials for aqua-feed is another important issue in terms of choosing sustainable and safe ingredients. The main ingredients of feeds for farmed carnivorous fish species are fish meal (FM) and fish oil (FO), at inclusion levels of about 25% and 30%, respectively. These two ingredients supply essential amino acids and fatty acids to the fish. Although the inclusion rates of FM and FO in aqua-feed have been progressively reduced in the recent past (in 1985 the inclusion rate was 60% for FM, and in 2005 the level of oil was 35-40%), at present over 50% of fish meal and over 80% of fish oil produced around the world are used in aquaculture (Jackson, 2007; Schipp, 2008; Koeleman, 2009) (**Figure 2**). World annual production of fishmeal and fish oil is about 6.5 million tons and 1.0 million tons, respectively, from 33 million tons of whole fish and trimmings (Schipp, 2008). Furthermore, recently, small quantities of FM and FO (3-5% and 1-3%, respectively) have been included in feeds for omnivorous and herbivorous fish (Koeleman, 2009). This generates one of the most-frequently cited issues with the sustainable development of aquaculture: *i.e.* the capture of other fish as raw material to be used as fish feed in the form of fish meal and fish oil. The sources of these ingredients (manufactured from wild-caught, small, bony/oily marine fish which are usually deemed not suitable for direct human consumption) in fact, are expected to remain static, or even decrease, making the supply of alternative proteins and fat sources for aqua-feed quite urgent.

A number of plant and animal proteins have some potential as FM and FO replacers. Thus for example, possible substitute of fish material include invertebrate animal by-products (*e.g.* silkworm pupae, earthworms, zooplankton), vertebrate animal by-products (*e.g.* blood meal, liver meal, meat and bone meal, poultry by-products), single-cell proteins (mainly from fungal and bacterial sources), oilseeds (*e.g.* soybean, rapeseed, sunflower, cottonseed), legumes (*e.g.* beans, peas, lupines) and miscellaneous plant protein

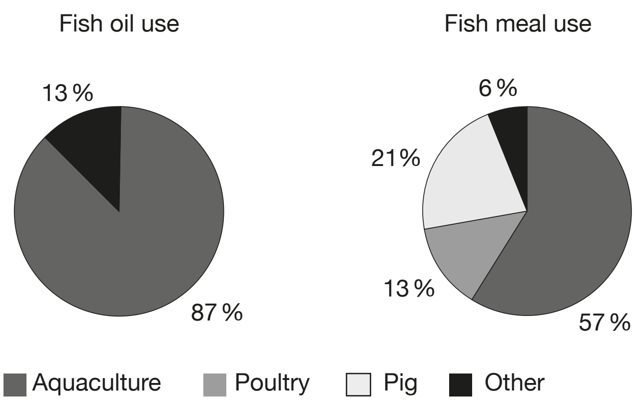

Figure 2. Global fishmeal consumption by feed sector in 2006 (IFFO data- Jackson, 2007).

products (*e.g*. corn gluten meal and concentrates made from potatoes and leaves) (New et al., 2002). Due to its high protein content and reliable supply, soybean meal is being widely used as the most cost-effective alternative for high-quality fish meal in feeds for many aquaculture animals. Different soybean products, such as soy protein concentrate, full-fat soybean meal, or low oligosaccharides soybean meal, have been tested in fish diets producing inconsistent and often conflicting results in terms of fish growth. The main reason for that in addition to the presence of the different quantities of anti-nutritional factors and/or low digestible carbohydrates present in these products, is the different sensitivity to soy antinutrients in various aquatic species (Chou et al., 2004). For example, in Atlantic salmon and rainbow trout, soybean meal has been found to cause a dose dependent morphological alternations in the intestine and impaired growth and protein utilization (Krogdahl et al., 2001). Dietary soybean meal also appears to stimulate immune responses because of inflammation in the distal intestine (Krogdahl et al., 2000), which makes its inclusion in salmonids aquafeed not always safe. When fat sources are considered, soybean oil is again an important source of vegetable fat (Soyatech, 2010), and contains higher levels of poly-unsaturated fatty acids than other types of vegetable oil, such as rapeseed oil or palm oil, but lacks eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), with linoleic acid (18: 2n-6) dominating at approximately 51-64%. As a consequence, soybean oil does not satisfy the essential fatty acid requirements of many marine fishes. Lack of these essential nutrients in the diet can affect negatively both fish health and the quality of products. FM and FO have been reported to offer major benefits to animal health, including improved immunity against disease, higher survival and growth, and reduced incidences of deformities (Schipp, 2008). In terms of seafood quality, the fatty acid composition in the flesh from farmed fish will also reflect the feed composition and inclusion of vegetable oil will reduce the level of omega-3 fatty acids. Therefore FM and FO are important ingredients in fish feed and can only to a limited extent be replaced in carnivorous fish diet by vegetable sources without reducing feed efficiency, fish growth, and products quality. Dietary substitution of FM and FO with alternative feed ingredient sources will be considerably easier for herbivorous/omnivorous aquaculture species than for carnivorous aquaculture species (Tacon et al., 2008). Notwithstanding the above, FM and FO are not essential feed ingredients *per se*, but rather have represented cost-effective providers of high quality animal protein and marine lipids packaged in near ideal nutritional proportions for most carnivorous and omnivorous high value aquaculture species (Tacon et al., 2008). The major challenge for the aqua-feed industry is going to be finding alternative feed resources that are sustainable and nutritionally equivalent to FM and FO while minimizing undesirable side effects such as slower growth, decreased animal health and changes to the nutritional content of the end product. Accordingly, several alternatives are being developed at a rapid rate and are increasingly being used to replace and supplement FM and FO in aqua-feeds, including also marine plants, which have enormous potential to act as fish feed ingredients (Schipp, 2008; Koeleman, 2009). The overall picture is therefore a gradual substitution of FM and FO in aqua-feed, which can increase both the sustainability and the eco-efficiency of aquaculture in the long run.

5. CONCLUSION

The competition between food, feed and fuel sectors for agriculture raw materials probably will affect the availability of feedingstuffs for animal production in the future. However, in the meanwhile new feed ingredients, mainly by-products, will become available for livestock animals and aquaculture farmed fish and their nutritional quality and safety remain to be more completely characterized. Accordingly, it would be essential not only to integrate and collate knowledge on feed quality (including safety) and feed supply, but also to promote the acquisition and facilitate the dissemination and sharing of information between research institutions, industry, farmers and consumer organizations. Proper production and use of these by- and co-products as feed ingredients have the potential to provide both the opportunity to formulate least-cost feed, and increase significantly their value. These two aspects will increase livestock and aquaculture sustainability and reduce negative impact on the environment.

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