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A model for risk-based monitoring of contaminants in feed ingredients

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ABSTRACT

A qualitative spreadsheet model has been developed for ranking feed ingredients on the basis of the potential risk of exceeding existing guidance or maximum levels in the EU for a certain contaminant, and the potential consequence of the presence of this contaminant on the health of animals and/or humans. The approach was based on the general concept of risk, being frequency times consequences of presence of the contaminant. Contamination of compound feeds due to presence of the contaminant in feed ingredients was estimated, per animal category, by: annual volumes of feed ingredients used for feed production, stratified per country of origin; the portion of each ingredient in compound feed formulations used for various animal categories; and the potential contamination of an ingredient per country of origin. The consequences of the contamination were accounted for by two consequence factors, both estimated per animal category: one for the potential impact of the contaminant on the health of the target animal, and one for the impact on human health, related to the possible formation of residues in animal derived food products.

The use of the model was demonstrated by its application to the presence of dioxins and dl-PCBs in compound feed for farm animals produced in the Netherlands in 2013 and 2014. Model results include the relative contribution, based on relative ranking scores, of each feed ingredient to the chance of exceeding limits and potential consequences on animal and human health. Feed ingredients ranking highest were palm oil, other fats and oils, dried products like bakery products, sunflower expeller/extracted, maize, and fish meal.

The model can be used by risk managers in feed industry and by governmental bodies for supporting decision making on the optimal allocation of resources for control of ingredients for compound feed production for presence of contaminants.

1. Introduction

Compound feed for farm animals can be contaminated by chemical substances – such as dioxins, heavy metals and mycotoxins – which may affect animal health and productivity, and also may be hazardous to human health in case the contaminant is transferred to animal derived food products. The presence of such toxic substances (contaminants) in animal feed is dependent on their presence in the ingredients used in the feed formulation and the inclusion rate of each ingredient, as well as feed production processes. Besides roughage, animal diets are largely based on compound feeds from cereal grains and co-products from food industry, e.g. soybean meal, bakery products and sugar beet pulp. Market, environmental and technological conditions – such as availability of feed materials, their country or region of origin, local weather conditions, and technological processes – show transient and structural changes over time. For example, in the last decade the use of cereal grains in animal diets in Europe, imported from Eastern Europe increased at the expense of imported tapioca meal from South East Asia. More recently, an increasing volume of rapeseed meal and dried distillers grain with solubles (DDGS) became available for inclusion in animal feed, resulting from the drastic increase in biofuel production. In addition, the increasing demand for agricultural raw materials for biofuel production and the rapidly growing livestock sector in developing countries cause a shift in the countries of origin from which feed ingredients are sourced and in global trade of feed materials. All such changes have a potential influence on the presence of chemical hazards in feed

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production and, consequently, on feed and food safety.

The aim of the current study was to develop a model for estimating the relative contribution of individual feed ingredients, used at the national level, in compound feed to the potential impact on animal and human health, related to the presence of a given contaminant in the feed ingredients. In principle the model aims at identifying those ingredients that may exceed maximum or guidance values, or may result in exceedance of maximum levels in animal derived food products.

2. Material and methods

2.1. General description of the model

A spreadsheet model was developed to estimate the relative contribution of feed ingredients of compound feeds for farm animals to the potential impact on animal health (including performance) and on human health related to the presence of a particular contaminant in feed ingredients. The impact score, and the relative ranking score per ingredient were calculated, using the HACCP (Hazard Analysis Critical Control Point) definition of risk, being presence (frequency/concentrations) of the contaminant times its consequences. Calculation of presence of the contaminant was based on: total volume of each feed ingredient used for compound feed production stratified to the country of origin, distribution of ingredients over compound feeds used for different animal categories, and potential contamination of ingredients with the specific contaminant, also related to the country of origin. Consequences for animals were expressed by the potential impact (in classes) of the contaminant on animal health, estimated per animal category. Consequences for humans were expressed by the potential impact (in classes) of the contaminant on human health, when consuming foods derived from animals, estimated per animal category. For this, exceedance of maximum or guidance values was used as the basis, since these values were set to protect the health of animals and humans. In practice, however, maximum levels for feed may aim primarily at avoiding too high levels in animal derived food products, rather than at protecting animals. This is e.g. the case for dioxins and aflatoxins, whereas for certain mycotoxins (e.g. deoxynivalenol) guidance values were set for feed ingredients, to avoid adverse effects in animals. Therefore, the model not only incorporates the possible non-compliance of feed ingredients to certain limits set for the presence of the contaminant, but also considers potential impacts to animals in the absence of specific animal-directed limits. Model results provide relative ranking scores per ingredient, which can be used to rank, feed ingredients based on their contribution to the potential impact on the health of animals and/or human (after consumption of food of animal origin), due to the contaminant of interest.

The impact score for a potential toxic contaminant in a given feed ingredient is calculated according to the general equations:

$$S_{all} = S_{human} + S_{animal}$$

Where,

$$S_{human} = \Sigma\,({}^{10}\log a \times b \times c \times \ \times d \times e_{human})$$
$$S_{animal} = \Sigma\,({}^{10}\log a \times b \times c \times d \times e_{animal})$$

With:

S_{all} = Overall score for impact to the health of animals (S_{animal}) and humans (S_{human}), taking into account the presence of the specific contaminant in specific feed ingredients from specific country of origins, for specific animal categories;

a = Total usage of the ingredient (continuous, kton);
b = Portion of feed ingredient per animal category (continuous, 0–1);
c = Portion of feed ingredient from a specific country of origin (continuous, 0–1);
d = Contamination factor representing the probability and level of occurrence of the contaminant in the ingredient in each country of origin (classes, values of 0.01 (low), 0.1 (medium), 1 (high));
e = Consequence factor of the contaminant per animal category for impact on health of animals (e_{animal}) or human (e_{human}) (classes, values of 0.01 (low), 0.1 (medium), or 1 (high));

Factor a represents the total usage of each of the feed ingredients. This volume of ingredients is expressed on a ^{10}log scale to avoid an overruling influence of raw materials commonly used in compound feed production in large volumes (e.g. maize, wheat and soybean meal). Factor b represents the relative distribution of a given ingredient over feeds used for different animal categories (e.g. broilers, laying hens, growing pigs). It is calculated based on the volume and composition of diets (feed formulation) assumed representative for the involved animal categories. Factor c represents the relative proportion of the ingredient imported from different countries.

The origin related contamination factor d represents the likelihood of relatively high levels of the particular contaminant in feed ingredients from a specific country, with three different levels being 0.01, 0.1 and 1 for each ingredient. This factor is assessed by expert judgement using literature and historical data, e.g. on analytical results for the contaminant of interest from (national) monitoring programmes, RASFF (Rapid Alert System for Food and Feed) notifications, and incident data. Circumstances during production and processing may also be considered but also the lack of knowledge of the production process (worst case assumption).

For the consequence of the contaminant (factor e), two factors are considered for each animal category; one for potential impact or effects on animal health and productivity (e_{animal}) and one for potential impact or effects on health of humans consuming animal derived products (e_{human}). Both consequence factors are assigned one out of three values, being 0.01, 0.1, and 1, i.e. low, medium and high, by experts, considering available data and scientific literature on residue transfer and accumulation, and toxic effects of the contaminant on animal and human. The consequence factor for animal health (e_{animal}) allows to take into account that animal species differ in sensitivity to potentially toxic components. For example, pigs generally are more sensitive to the mycotoxin deoxynivalenol (DON) than poultry and ruminants, hence, the value of the consequence factor e_{animal} for this mycotoxin would be higher for pigs than for other species (which is also reflected in the guidance values set by the EC). The consequence factor for humans (e_{human}) covers potential accumulation of residues of the contaminant in animal derived foods, and the potential impact of the contaminant on human health when consuming contaminated animal derived foods.

In the model, the total impact score (S) for the contaminant of interest in a given feed ingredient is determined for all animal categories and all countries of origin, using the cumulative results of Equation. Subsequently, the relative contribution of each ingredient to the total impact score of a contaminant is calculated and ingredients are ranked on the basis of their contribution.

2.2. Application of the model to dioxins and dl-PCBs

The model was applied for ranking feed ingredients of compound feed used in the Netherlands in 2013 and 2014, as regard their impacts due to contamination with polychlorinated dibenzo-p-dioxins and dibenzofurans (dioxins) and dioxin-like PCBs (dl-PCBs). In a series of opinions on risk based monitoring in meat inspection, these contaminants were classified by EFSA as the highest priority when it comes to chemical contaminants (EFSA, 2011, 2012, 2013). The necessary data were collected for compound feed production in the Netherlands in those years, with ingredients imported from all over the world. Information on the collected input data is given in the following sections.

2.2.1. Volume, origin and distribution of ingredients over animal categories

Data on the total usage of feed ingredients and on the origin of these feed ingredients were derived from a national database, provided by the Dutch Product Board for Animal Feed (PDV) (see, http://www.pdv.nl/), and the database from Eurostat (see, http://ec.europa.eu/eurostat/). Data comprised of volumes of home produced feed ingredients, imported feed ingredients, and imported raw materials that are processed in the Netherlands, e.g. soybean meal from crushing soybeans imported from South America. In principle, the total use of feed ingredients in compound feeds can be determined based on total compound feed production and their composition for the major animal categories in the Netherlands. Total volumes of the compound feeds for major production animals, were derived from the database for compound feed production for those animal species in the 28 EU member states, collected and presented on an annual basis by the European Feed Manufacturers' Federation (FEFAC) (http://www.fefac.eu/). Data on the relative use of each feed ingredient for compounds feeds for different animal species (factor b) were not publicly available. Therefore, least cost optimisation was applied to determine the composition of complete diets for the different main animal categories, being pigs, poultry, cattle, and other animals, and their subcategories (Table 1), at quarterly intervals, based on actual market prices and availabilities of ingredients, and nutrient standards used by feed industry (e.g. CVB, 2010). Formulating a compound feed in animal production involves determining a mix of ingredients meeting specific nutrient requirement, per animal category, in accordance with production objectives. The amounts of nutrients that each ingredient will supply to the animal's metabolism and the amount of nutrients in the complete feed needed by the specific animal category were derived from tables of feed ingredients and nutrient recommendations (CVB, 2010). For feed formulation, linear programming was then used to determine the level of incorporation of each available ingredient that, by respecting a series of linear constraints, will minimize an objective function, typically the costs of the mix. Ingredients are thus selected on the basis of their availability, composition and costs (Pomar, Dubeau, Létourneau-Montminy, Boucher, & Julien, 2007).

The results were discussed with experts from compound feed industry in the Netherlands to assure that the composition of these optimised complete feeds was indeed representative for commercial feeds for the respective animal categories. As a check, data on total availability and use of feed ingredients (see above) were compared with the total use on the basis of least cost optimisation. If needed, boundaries of the least cost optimisation were adjusted to represent practical conditions. In this way, the distribution of the total volume of each ingredient over the compound feeds for the different animal categories was determined. For ingredients without any information on the distribution among animal categories, this distribution was assumed to be proportional to the total volume of feed used for each animal category.

2.2.2. Contamination of feed ingredients, per country of origin

Data from monitoring programmes on the presence of chemical contaminants in feed materials, both from the competent authority and from feed industry in the Netherlands, were available for use in this study. Data collected by feed industry covered the database of a feed industry organisation (Securefeed and its legal predecessors), representing the largest compound feed producers in the Netherlands, in total accounting for about 80% of the compound feed produced in the Netherlands. Both sources of data had been used previously to evaluate trends in concentrations of dioxins and dl-PCBs (Adamse, De Jong, Jongbloed, Van Raamsdonk, & Van Egmond, 2007, 2015) in a selection of feed ingredients over time. The data and results from such trend analyses provide insights into probabilities of contamination and concentrations (per contaminant) for different feed ingredients and countries of origins. Also, information from published results of chemical analysis of dioxins and dl-PCBs was used, RASFF notifications, as well as information on the involved feed production processes, quality assurance etc. for the different countries of origins and ingredients. Using these sources of information, the contamination factor (factor d) was estimated by expert judgement for each ingredient per country of origin, for both 2013 and 2014. The entire input table, derived from expert estimates, on the contamination factor per feed ingredient and country of origin includes 85 ingredients $\times$ 69 countries of origin. As an example, in 2013 for the Netherlands, a contamination factor of 1 was used for dried bakery products, fish meal, fish oil, coconut fat, palm oil, and palmkernel fat. The value of 0.1 was used for processed soybeans, soybean oil, rapeseed expeller, rapeseed oil, sunflower oil, mixtures of fats and fatty acids, and premixes, and 0.01 was used for the remaining ingredients. For each ingredient, values of the contamination factor varied between the country of origin. For some countries and ingredient combinations, assigned values of the contamination factors were slightly different in 2014.

Table 1
Animal categories and subcategories for which compound feeds were included in the least cost optimisation to estimate the distribution of ingredients over compound feeds.

- Pigs
  - starter diets for weaned pigs
  - grower, early and late finisher diets for growing pigs
  - diets for gestating and lactating sows
- Poultry
  - a mean broiler diet based on a four phase feeding programme
  - diets for laying hens below and above 18 weeks of age
  - diets for broiler breeders below and above 18 weeks of age
  - a mean turkey diet based on a five phase feeding programme
- Cattle
  - low and high protein diets for dairy cows and diets for cattle breeding stock
  - grower and finisher diets for pink veal calves and veal cows and steers
- Milk replacers
- Others
  - diets for goats, sheep, horses

Values of factors a, b, and c (volumes, usage and origins) were also updated for the two years, calculated from the available data (mentioned earlier).

2.2.3. Consequences of the contamination with dioxins and dioxin-like PCBs

Consequence factors for the potential impact of dioxins and dl-PCBs on animal health (e_{animal}) and on human health (e_{human}) were assigned one out of their three possible values, per animal category (Table 2), based on literature and expert opinion, the reasoning of which is explained below. Dioxins are unintentional by-products of industrial processes, including from the burning of certain waste materials. Various incidents occurred in the past due to the use of inappropriate fuels for drying of feed materials (Hoogenboom, Traag, Fernandes, & Rose, 2015a). PCBs were produced in large amounts in the past and may still be present in old transformers, heat exchange equipment but also in certain paints and isolation kits. Dioxins and dl-PCBs are generally regarded as highly toxic to human health at relatively low levels. The wide range of reported adverse effects include immunotoxic, neurodevelopmental, endocrine and carcinogenic effects (Rysavy, Maaetoft-Udsen, & Turner, 2013; WHO, 2014). Effects have been observed at high intake levels, but a low intake over a longer period (chronic exposure) is considered to result in similar toxic effects because of the low degradability and accumulation of a number of dioxins and dl-PCBs. Food of animal origin is the predominant source of the dioxin and dl-PCB intake by human consumers, due to accumulation in liver and fat containing tissues, and excretion in milk and eggs (Malisch & Kotz, 2014). Maximum levels for dioxins and for the sum of dioxins and dl-PCBs have been set in the EU for animal derived foods in Regulation EC No 1881/2006 (EC, 2006) and its amendments, the most recent ones being 1259/2011 (EC, 2011) and 1067/2013 (EC, 2013). Levels of dioxins and dl-PCBs in feed materials are regulated by Directive 2002/32/EC (EC, 2002) and its amendments (currently the last amendment is in Regulation EC No 277/2012 (EC, 2012)). Because of the rapid and relatively high transfer to milk (Adekunte, Tiwari, & O'Donnell, 2010; Kan & Meijer, 2007; Hoogenboom et al., 2015b) and eggs (Hoogenboom, Kan, Zeilmaker, Van Eijkeren, & Traag, 2006), the consequence factor e_{human} was set to 1 for milk producing cattle and goats, and for laying hens. Although these contaminants also accumulate in meat and liver, it was judged that the chance of this leading to exceedance of MLs was somewhat lower, thus leading to a value of 0.1 for meat producing animal species (Table 2). This is also supported by the fact that animals raised for meat production are continuously growing, thereby diluting the levels in the meat (see e.g. Hoogenboom et al., 2007 for growing pigs). This also means that in particular the feed in the last stage of production is relevant, unless the levels in feed used at an earlier stage are very high. This is quite opposite from the continuous production of milk and eggs and the concentrating of the compounds in the lipid fraction of milk and especially eggs. In terms of adverse effects on animals, poultry seems to be the most sensitive farm animal species, as indicated by a number of incidents showing chicken oedema disease caused by dioxins. In addition, reduction in egg hatchability, along with reduced weight gain and increased mortality of chicks has been reported. These birds presented with ascites, subcutaneous oedema of the neck and neurological disturbances (ataxia). Histology revealed degenerative changes of the skeletal and cardiac muscles (Bernard et al., 1999; Firestone, 1973; Guitart et al., 2010). Cattle and pigs seem to be less sensitive, although it must be noted that subtle effects of long-term exposure to low levels of dioxins and dl-PCBs may easily be missed. Consequently, the factor e_{animal} was set at 0.01 for all animal categories except for all types of poultry (broilers, laying hens and broiler breeders) for which it was set at 0.1 (Table 2).

Table 2
Assigned values for the consequence factors for presence of dioxins and dl-PCBs in feed for different animal categories, for effects on health of both animals and humans.

	Animal	Human
Piglets	0.01	0.1
Growing-finishing pigs	0.01	0.1
Rearing gilts	0.01	0.1
Sows	0.01	0.1
Broiler	0.1	0.1
Broiler breeders	0.1	0.1
Laying hens	0.1	1
Dairy cows	0.01	1
Young dairy	0.01	0.1
Beef cattle	0.01	0.1
Veal calves	0.01	0.1
Sheep	0.01	0.1[a]
Goat	0.01	1[a]
Horses	0.01	0.01

[a] Concerns sheep for meat production, and goat for milk production.

3. Results

Overall results of applying the model to the case of dioxins and dl-PCBs are presented in Table 3, presenting the top ten feed ingredients contributing most to the total impact scores for these contaminants in compound feed used in the Netherlands in 2013 and 2014, respectively. Results for 2013 are illustrated in Fig. 1 for animal and human, separately.

In 2013, the total impact score for dioxins and dl-PCBs was 5.2 (arbitrary units) of which 72% resulted from the 10 ingredients ranked highest. Palm oil (14%), mixtures of fat(ty acids) (13%), miscellaneous plant oils, including linseed oil (9%), maize (8%) and sunflower expeller/extracted (7%) contributed most to the total impact score. The largest part of the total score (4.5, 87%) was related to potential impact on human health (R_{human}); the relative contribution of the impact on health of target animals (R_{animal}) accounted for the remaining part (0.7, 13%). The impact for human health related to dioxins and dl-PCBs is primarily due to the contamination of eggs and milk because of the high transfer of these contaminants to these food products, easily leading to exceedance of the maximum or guidance levels at elevated feed levels. From Table 3 it can be seen that the ten feed ingredients that had the highest impact score do not differ much between the two years, although their relative ranking was slightly different. These differences were caused by volumes used, countries of origin, inclusion in feed for particular animal categories, and/or (slight) differences in the values of the contamination factors per country between the two years. As an illustration, in 2013 the total impact scores for palm oil (0.71) and for maize (0.41) were quite comparable, but total usage of maize was much higher (2563 ktons) than the usage of palm oil (33 ktons). Since the contamination factor for palm oil was set at the highest level for all countries of origin, contrary to maize, the total usage × country of origin × contamination factor per country were in the same order of magnitude. Both ingredients are mainly used in the diet for animals with a high consequence factor, though for different animal categories. E.g., in 2013, 25% of all maize was used in complete feeds for laying hens, 15% for broilers and 15% for dairy cows, whereas 29% of all palm oil was used in feeds for laying hens, 29% for broilers, and 0.4% for dairy cows.

Further comparison of results for 2013 and 2014 shows that the major difference in the top 10 feed ingredients is in the fats. In 2013, mixtures of fat(ty acids), pig fat and other sources of animal fat (not

Table 3
Top ten of feed ingredients used in compounds feed in the Netherlands in 2013 and 2014, estimated to have the highest relative contribution to the impact of dioxins and dl-PCBs on animal and human health (ingredients listed from highest to lower rank).

2013			2014		
Feed ingredient	Impact score (S_{total})	Usage (kton)	Feed ingredient	Impact score (S_{total})	Usage (kton)
Palm oil	0.707	33	Palm oil	0.927	34
Mixtures of fat (ty acids)	0.673	21	Miscellaneous plant oils, incl. linseed oil	0.889	29
Miscellaneous plant oils, incl. linseed oil	0.474	28	Poultry fat	0.656	22
Maize	0.412	2563	Sunflower expeller/extracted	0.645	497
Sunflower expeller/extracted	0.366	481	Maize	0.506	2645
Bakery products	0.269	276	Sugar cane molasses	0.441	127
Other animal fat (not beef, pig, poultry)	0.231	17	Bakery products	0.270	285
Rumen-protected rapeseed extracted	0.195	178	Rumen-protected rapeseed extracted	0.201	184
Pig fat	0.191	28	Fish meal	0.182	8
Fish meal	0.176	8	Bovine fat	0.181	45

pig, beef and poultry) were in the top 10, whereas these ingredients were not in the list with 10 ingredients ranked highest in 2014. Instead, in 2014, poultry fat and bovine fat as well as sugar cane molasses were in the top 10. Differences in the two years were mainly caused by differences in the extent to which the different sources of fat were used in diets for particular animal categories. Sugar cane molasses is mainly used in diets for growing pigs and dairy cows. In 2014, it was used to a higher extent in the feed for dairy cows, having a higher consequence factor, and to a lower extent in feed for growing pigs, having a lower consequence factor, as compared to 2013. For 2013 and 2014, the percentages for dairy cow feed were 22% and 38%, respectively, whereas for pig feed, these percentages were 48% and 35%, respectively. In both years, the remaining part of the sugar cane molasses were used in small percentages in the diets for the other animal categories with lower consequence factors. Also, the total volume used in 2014 is a slightly higher than in 2013.

To assess the sensitivity of the model to values of the model parameters, the two parameters that are assigned values to by experts, i.e., the consequence factor (d) and the contamination factor (e), were evaluated. Parameters values a, b, and c are derived from ‘hard’ data, and therefore uncertainty of these values are relatively smaller. Model calculations were done using the actual values of parameter d and e, but also using a class higher (if possible) and a class lower (if possible), all one by one, and the top 10 of feed ingredients with the highest relative impact score was evaluated. An example outcome of this sensitivity analyses, as far as related to changing the consequence factor for the animal category of finishing pigs, is presented in Table 4. . In reality every possible combination has been tested. Results showed that in general the relative effect of changing the value of the contamination factor (d) is smaller than the effect of changing the value of the consequence factor (e).

4. Discussion

The current model provides a tool that can be used by risk managers to support risk based monitoring of contaminants in ingredients of animal compound feed, to ultimately minimize exposure of farm animals and humans to the contaminants. The results of the model give insight into the relative contribution of each feed ingredient to the total impact – posed by a specific contaminant in the ingredients to animal and human health, through compound feed given to production animals. The impact accounts for the presence of the contaminant in feed given to particular groups of production animals, and possible effects on the health of animals, and/or of humans, through the transfer of the contaminant in the animal’s body to animal derived food products. The benefits of using the model, over using volume and contaminant data only, are due to also including contaminations per country of origin; inclusion rates of the various raw materials in compound feeds for different animal categories; and the consequences for animal and human health. Relative risk scores of ingredients have arbitrary units which can be used to rank ingredients; they cannot be used for comparison of risks related to multiple contaminants in feed ingredients. It should also be noted that the model identifies feed ingredients that can potentially contribute to a risk, e.g., due to a drying process which may be done incorrectly. This does not imply the ingredient is always contaminated, but that risk managers should be aware of the chance. Real validation of the model would therefore take considerable effort.

In the model different farm animal categories are distinguished, because animals differ in: i) their sensitivity to toxic substances, and ii) carry-over of the contaminant to food products derived from the particular animal (e.g. milk, meat and eggs). A feed ingredient can be highly contaminated with a specific contaminant, but still the presence of this contaminant in animal derived food products can be low, e.g. when the ingredient is scarcely used in the particular animal diets and/or if transfer of the contaminant to animal derived food products is low. This allows a relatively low emphasis on monitoring this feed ingredient. For instance, for the mycotoxin DON, a high value should be assigned for the consequence factor (e_{animal}) for sows, given the effects of the toxin on sow (re)productivity, resulting in this factor being 1 for these animals. However, the consequence factor for human (e_{human}), expressing the accumulation of residues in food derived products from sows (in this case meat) is low, given the very low transfer of DON in sows to pork meat. The mycotoxin AFB1 is given a high value for d_{human} for dairy cows, because of the high rate of transfer of its metabolite AFM1 to milk and the potential carcinogenic effects of AFM1 on humans. Since direct effects of AFB1 on dairy cows’ health are relatively low, the d_{animal} is assigned a low value (0.1).

The values for contamination of an ingredient (factor d) were estimated by expert judgement, who used results from peer-reviewed literature, monitoring programs and feed safety incidents, e.g. as reported in the RASFF-system (http://ec.europa.eu/food/safety/rasff/) or in the literature. For adapting the factors, also (inter)national databases with results from monitoring programs on contamination of feed ingredients can be used as well as results from trend analyses based on these data, e.g. as performed by Adamse et al. (2007, 2015). To be more proactive, relevant information regarding the production process, climatic conditions, quality control in the respective countries, etc. should be used rather than using data from historical incidents. When data or information are not available for the particular country, the expert can make a best guess. With the estimation, the pre-cautionary principle can be considered, and worst case values could be

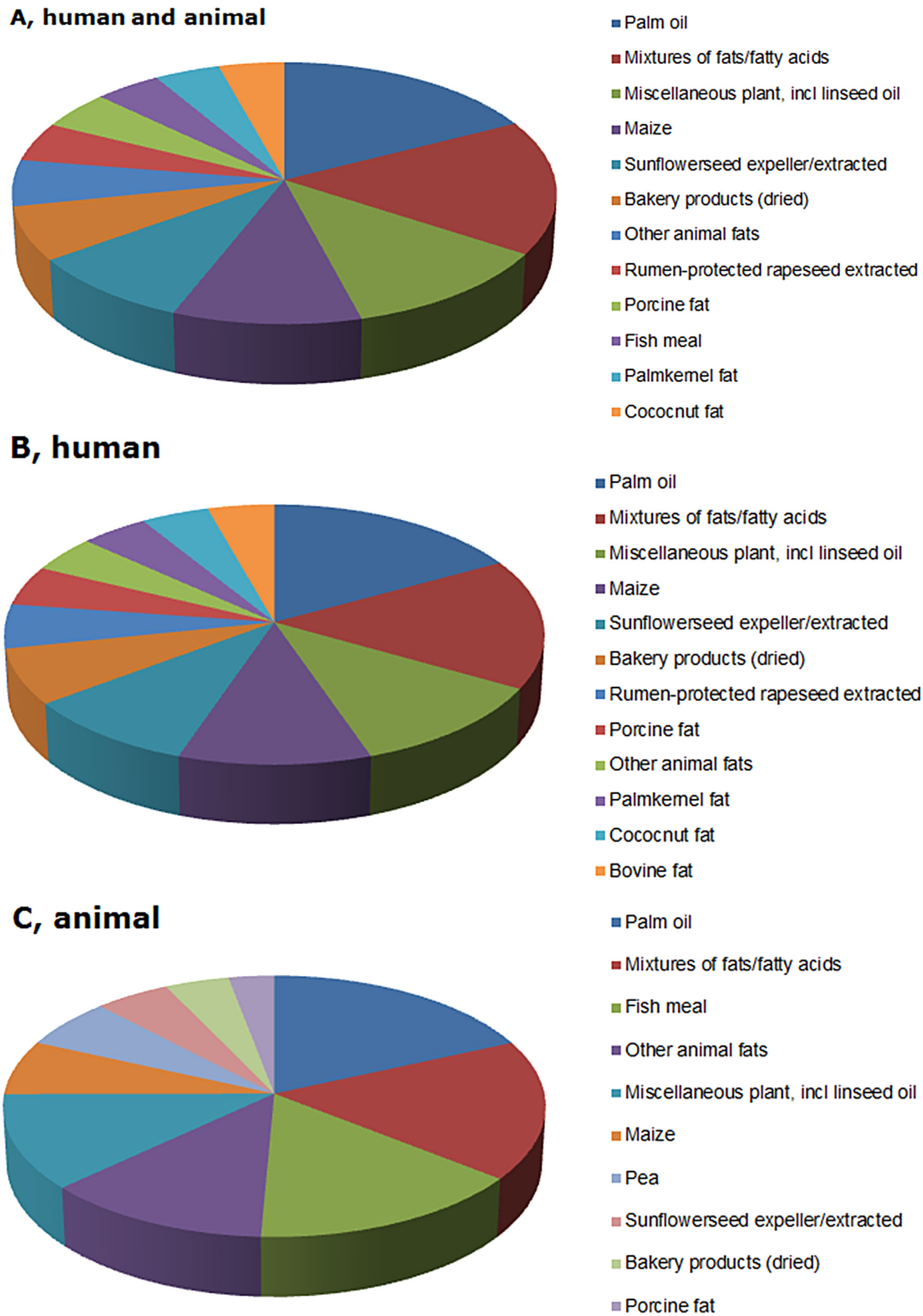

Fig. 1. Relative contribution of the ten feed ingredients with the highest impact score related to the presence of dioxins and dl-PCBs in animal feed produced in the Netherlands in 2013. A: considering consequences on both animal and human health, B: considering consequences on human health, C: considering consequences on animal health.

assigned to the contamination factors until such information becomes available. In the current example, a case on dioxins and dl-PCBs in feed used in the Netherlands in 2013 and 2014, a worst-case value was assigned to all feed ingredients from a particular country, since – unless otherwise proven – feed ingredients sourced from this countries are relatively suspected compared to

Table 4
Example output of the sensitivity test of the model varying the consequence factor for dioxins and dl-PCBs for the category of growing finishing pigs.

Rank	Value consequence factor, for growing finishing pigs		
	Actual value	One class lower	One class higher
	0.01	0	0.1
1	Palm oil	Palm oil	Bakery products
2	Fish meal	Fish meal	Palm oil
3	Palmkernel fat	Palmkernel fat	Palmkernel fat
4	Maize	Maize	Fish meal
5	Peas	Peas	Maize
6	Sunflowerseed meal	Sunflowerseed meal	Coconut fat
7	Coconut fat	Coconut fat	Fish oil
8	Bakery products	Fish oil	Peas
9	Fish oil	Soybean oil	Sunflowerseed meal
10	Soybean oil	Miscellaneous plant, incl linseed oil	Soybean oil

those from other countries. Results of this example case showed that feed ingredients with the highest relative impact score include various types of fats and oils, some dried products (e.g. bakery products, maize, peas, rapeseed) and fish meal, which, depending on area of origin, may be substantially contaminated (prevalence factor was 1.0 or 0.1 depending on the area of origin). All farm animal categories, but in particular poultry (laying hens) and dairy cows, were relevant with respect to the possible contamination of animal derived products.

In addition to dioxins and dl-PCBs, the model was also applied to the mycotoxins DON and AFB1 (results not shown). For these two mycotoxins, the ranking of feed ingredients showed different results. Specifically, wheat (products) and barley were ranked highest for DON, whereas maize, sunflower expeller/extracted and palm kernel expeller/extracted were ranked highest for AFB1. Other or new feed ingredients can be added to the model, but information on contamination of the feed ingredient from various countries of origin is then also needed. Consequences of new insights and data on relative contribution of feed ingredients to total impact can be estimated. In the example case, historical data on imported volumes and use of feed ingredients were used. Nonetheless, the calculation model allows to include expected changes in the production and use of feed ingredients, e.g. due to weather, production processes, alternative use of ingredients (biofuels), use of new feed ingredients, other countries of origin, and to calculate the consequences of these developments on the relative ranking of ingredients.

The current model was initially developed to support the national competent authority in the Netherlands to conduct official quality controls of animal feed and feed ingredients, taking account of risks associated with animals, feed or food, as required by Regulation (EC) No 882/2004. The model is in use by the Netherlands Food and Consumer Product Authority for three years now. Model results are used to help decision making upon the national risk based monitoring program for contaminants in animal feed and feed ingredients on an annual basis. More specifically, model output - in terms of the ranking of the feed ingredients – provide an indication for feed ingredients that need to be sampled most for the particular contaminant. Moreover, for priority feed ingredients, the model also provides guidance to focus sampling on countries of origin with relatively high values for contamination, e.g. for aflatoxin B_1 in maize from some South and Eastern European countries.

The model could also support dedicated monitoring of feed ingredients within a feed producing company. Depending on the aim, the risk manager can select the appropriate data for use in the model's datasheets. To this end, the model is made flexible and user friendly, so user data can easily be included and used in the model calculations.

5. Conclusions

This study describes a transparent and flexible qualitative model to estimate the relative contribution of different feed ingredients to the potential impact on the health of farm animals and/or humans (when consuming animal derived foods), as related to the presence of a specific contaminant in the raw materials Volume and origin of feed ingredients and the use of ingredients for feeds for different animal categories with different sensitivity to the contaminant and transfer of the contaminant to food products are included. The model can be helpful to support decision making, both by governmental bodies and feed industry, on the optimal allocation of resources for monitoring the safety of animal feed ingredients.

Conflict of interest

None.

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