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Risk ranking of chemical hazards in food and feed – A case study in cereals in the Netherlands

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ABSTRACT

Monitoring programs for food safety hazards in feed and food are increasingly performed on a risk-basis. Various methods are available to rank hazard-product combinations to be included in risk-based monitoring programs. Such methods have been developed for either feed or food, but until now these do not consider hazards in both feed and food simultaneously. Based on available time, budget and data, two methods, i.e. a scoring method and a risk ratio method, were selected that are capable of incorporating both food and feed products for ranking chemical hazards. These methods were compared by applying a case study on chemical hazards in cereals in the Netherlands for various animals and human age groups, using available data on concentrations, consumption available in national databases and toxicity. Results showed that both methods resulted in the highest ranking for the mycotoxins deoxynivalenol, aflatoxin B1 and zearalenone. Maize and wheat products were most frequently included in the top 50 ranked hazard-product combinations. Both methods showed to be capable of ranking hazard-product combinations for various animal and human groups. The risk ratio method provided a more objective and accurate outcome since it is based on actual data. Nevertheless, the risk scoring method may be preferred as it allows more flexibility in type of input data used. Also, it allows for the inclusion of country of origin of the materials used, which is relevant for imported products. This study showed that the risk ratio and the scoring method can successfully be used to rank both food and feed products simultaneously.

1. Introduction

Concerns related to food safety have been expressed centuries ago and food safety practices were already applied by the ancient Greek, Roman, Chinese and Egyptians. When food became more industrialised, regulation regarding food safety, sanitary and hygiene were implemented (Mahmoud, 2020). Despite all efforts in reducing food safety risks, zero risk cannot be achieved. Indeed, the 2015 report of the World Health Organization (WHO) indicates that at the global and sub-regional level, 600 million cases of foodborne illness could occur yearly as well as 420,000 deaths (WHO, 2015). Apart from human health effects, significant costs can be related to a foodborne outbreak. The 2011 outbreak of *Escherichia coli* O104:H4 in Germany, for example, also had major consequences on other European Member States. Spanish authorities estimated a product loss worth of 200 million Euro and additional costs for produce withdrawal of 51 million Euro (Karch et al., 2012). Apart from microbiological hazards, chemical hazards may also be found in food and feed, which may impact human health. The difference is that microbial hazards usually result in acute effects that may ultimately lead to foodborne outbreaks whereas chemical hazards usually have long-term effects. This complicates assessing their human health risk. Furthermore, a top-down approach based on epidemiological data is difficult since cause-effect relationships are less straightforward than for microbial hazards (Lindqvist et al., 2020). A study by the WHO used disability life years (DALYs) to compare four chemical hazards in 2010 showing that aflatoxins had the highest disease burden (Gibb et al., 2015). The various dioxin incidents in the past showed that monitoring food and feed is needed to identify gaps and weaknesses in the production chain as well as capture potential incidents at an early stage to minimize human health risks and reduce accompanying costs (Heres et al., 2010). Therefore, monitoring chemical hazards is needed to prevent human health risks. However, budgets for monitoring food products are not unlimited; so, not all potential chemical products and food products can be monitored. As a result, monitoring plans are increasingly risk-based focusing on the most relevant hazard-food combinations to include (van Asselt et al., 2021). Studies have shown that such risk-based monitoring plans are cost-effective. Alban et al. (2016) showed that a more costly, but higher sensitive analytical method could be applied at

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the same costs when a risk-based monitoring program is applied. Therefore, even though methods are more costly, they could still be applied as they may be more cost-effective. A risk-based inspection related to zoonotic parasites also showed to be more cost-effective: when focusing on high-risk animals, fewer meat inspections were needed as well as lower microbial contaminations of the products and thus positively affecting human health (Chengat Prakashbabu et al., 2018).

For a risk-based monitoring program, first of all, hazard-product combinations need to be ranked based on their potential risk. Risk in this case is defined as a combination of the probability of occurrence and the potential health effects. Various methods are available for risk ranking as previously reviewed by Van der Fels-Klerx et al. (2018). Methods can be qualitative requiring less time, budget and data than quantitative methods. Examples of qualitative methods are the use of decision trees or expert elicitation. On the other side of the spectrum, quantitative methods are based on large datasets, which require a substantial amount of time and budget. However, these methods are usually more objective and transparent. In between qualitative and quantitative methods are the so-called semi-quantitative methods. These methods are usually based on scores and examples are risk matrices and multi-criteria decision analysis (Van der Fels-Klerx et al., 2018). Risk ranking methods developed and applied for chemical hazards usually target either food or feed. For food or feed companies such methods are helpful to establish their monitoring program. However, national food safety authorities have the responsibility to ensure human and animal health. Therefore, they need to allocate resources for monitoring both food and feed. The outcome of the separate rankings in food and feed cannot be simply added to come to a combined ranking. Currently, there is no method available that is capable of ranking food safety hazards in both food and feed. A combined method that simultaneously ranks food and feed products allows for a substantiated resource division related to health risks as input to a risk-based monitoring program.

The aim of the current paper was to determine whether chemical hazards could be ranked in a combined output for both food and feed. Based on available time, budget and data, two methods were selected for this purpose and the results were compared. A recently developed quantitative method for ranking chemical hazards in food (Hobé et al., 2023) was applied for feed materials and - *vice versa* - a previously developed semi-quantitative method for ranking chemical hazards in feed materials (Van der Fels-Klerx et al., 2017) was applied to food products. This allowed the comparison between two different types of methods (quantitative versus semi-quantitative) and two different perspectives (a method developed for food versus a method developed for feed).

2. Methods

2.1. Case study

In order to compare the two risk ranking methods for prioritizing chemical hazards in food and feed, a case study was defined for which both the quantitative method and the semi-quantitative method were applied. The methods were applied to rank hazard-food/feed combinations for one group of products, i.e. cereals. Cereal products were chosen since these products are both consumed by humans and animals and can thus be applied for food and feed. Chemical hazards relevant for cereals are mycotoxins and heavy metals. The case study included those heavy metals and mycotoxins that had sufficient data for the ranking i.e. lead, cadmium, aflatoxin B1, Deoxynivalenol (DON), Ochratoxin A, T-2 toxin and HT-2 toxin, and Zearalenone (ZEA)) The case study was applied to the Netherlands as an example.

2.2. Risk ranking methods

Two previously developed risk ranking methods were applied: a quantitative method based on the risk ratio methodology using hazard quotients (Hobé et al., 2023) and a semi-quantitative method (the RiskFeed model) based on scores for probability and severity of the hazard (Van der Fels-Klerx et al., 2017). Both methods used the same human and animal groups. Humans were divided in 4 different age groups: adults ($\geq$ 18 years), adolescents (13-17 years), children (4-12 years) and toddlers (1-3 years). Animals were divided analogous to the age-species groups included in the RiskFeed model (Van der Fels-Klerx et al., 2017) into: piglets, grower-finisher pigs, gilts, sows, broilers, laying hens, breeder hens, dairy cows, young bovines, beef cattle, veal calves, sheep and goat. The methods used are further described below.

Risk ratio method (Hobé et al., 2023)

For both food and feed, hazard quotients (HQ) were calculated using the estimated daily intake (EDI) for humans and animals, the health based guidance value (HBGV) or the reference point for potential health concern (RPHC) for humans or the No Observed Adverse Effect Levels (NOAELs) for animals:

$$HQ = \frac{EDI\left(\frac{\mu g}{day}\right)}{HBGV\ or\ RPHC\ per\ contaminant\ (\mu g/kg\ bw/day) * bodyweight\ (kg\ bw)} \tag{1}$$

The EDI was established per food or feed product as:

$$EDI\left(\frac{\mu g}{day}\right) = Concentration\ of\ contaminant\ per\ product\left(\frac{\mu g}{kg}\right) * \frac{Consumption\ per\ product\left(\frac{g}{day}\right)}{1000} \tag{2}$$

The HQs were estimated separately for each human age group and for each animal group considering the average body weight of that group and the average consumption of the particular product in gram/day for each group, separately. The average body weight for humans was obtained from Van Rossum et al. (2020). For animals, the average body weight was obtained from KWIN-AGV 2022 - WUR and StatLine.

Scoring method (Van der Fels-Klerx et al., 2017)

The previously developed RiskFeed method was applied to estimate the Risk scores per contaminant and product as:

$$Risk\ score = \left(\frac{\log a}{\log a_{totaal}}\right) * b * \sum (c * d)_{country} * e$$

With a: total amount of feed or food used in the Netherlands (kton/year)

b: portion of feed ingredient per animal category or portion of food product per human age group (%)
c: portion of feed or food product imported per country (%)
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 for animals (e_animal) or for human (e_human) (classes, values of 0.001 (very low), 0.01 (low), 0.1 (medium), or 1 (high)) analogous to Van der Fels-Klerx et al. (2017). Further explanation is provided in section 2.3.3 below.

2.3. Input data

2.3.1. Consumption data

For food, consumption data of the Dutch National Food Consumption Survey (VCP) data of 2012–2016 were used (Van Rossum et al., 2020) in both the risk ratio and scoring method. For the scoring method, the total food consumption in the Netherlands and the proportion of food ingredients/products for adults, adolescents, children, and toddlers was derived from the VCP. The total food consumption was multiplied by the number of citizens in the Netherlands, based on Statistics Netherlands (CBS) data retrieved on 4 February 2022 (CBS, 2022a).

Table 1
Top 50 for ranking food and feed using the risk ratio method.

Rank	Type	Product	Chemical hazard	Group	concentration (mg/kg)	consumption (g/day)	HBGV or RPHC (mg/kg bw/day)	weight (kg)	HQ
1	food	Wheat, bread	Aflatoxin B1	Toddlers (1-3 years)	3.53E-04	81.7	4.00E-08	13.8	52.26
2	food	Wheat, bread	Aflatoxin B1	Child (4 -12 years)	3.53E-04	115.6	4.00E-08	34.3	29.73
3	food	Rice (products)	Aflatoxin B1	Toddlers (1-3 years)	2.33E-03	5.8	4.00E-08	13.8	24.34
4	food	Wheat, bread	Aflatoxin B1	Adolescents (13-17 years)	3.53E-04	143.5	4.00E-08	64.3	19.69
5	food	Rice (products)	Aflatoxin B1	Child (4 -12 years)	2.33E-03	11.1	4.00E-08	34.3	18.90
6	food	Rice (products)	Aflatoxin B1	Adults (≥ 18 years)	2.33E-03	20.0	4.00E-08	81.2	14.36
7	food	Wheat, bread	Aflatoxin B1	Adults (≥ 18 years)	3.53E-04	127.9	4.00E-08	81.2	13.90
8	food	Rice (products)	Aflatoxin B1	Adolescents (13-17 years)	2.33E-03	12.6	4.00E-08	64.3	11.38
9	food	Wheat, bread	ZEA	Toddlers (1-3 years)	2.41E-01	81.7	2.50E-04	13.8	5.72
10	food	Pasta	Aflatoxin B1	Toddlers (1-3 years)	1.79E-04	13.9	4.00E-08	13.8	4.51
11	food	Pasta	Aflatoxin B1	Child (4 -12 years)	1.79E-04	29.1	4.00E-08	34.3	3.79
12	feed	Maize	DON	Fattening pigs	9.69E-01	586.5	1.23E-03	125	3.71
13	food	Wheat, bread	ZEA	Child (4 -12 years)	2.41E-01	115.6	2.50E-04	34.3	3.25
14	feed	Maize gluten feed	DON	Beef cattle	5.79E+00	766.1	1.77E-03	791	3.17
15	food	Breakfast cereals	Aflatoxin B1	Toddlers (1-3 years)	2.86E-04	5.9	4.00E-08	13.8	3.08
16	feed	Maize	DON	Beef cattle	9.69E-01	4266.0	1.77E-03	791	2.95
17	food	Pasta	Aflatoxin B1	Adolescents (13-17 years)	1.79E-04	41.8	4.00E-08	64.3	2.90
18	feed	Maize	DON	Sows	9.69E-01	592.2	1.04E-03	230	2.40
19	food	Wheat, bread	ZEA	Adolescents (13-17 years)	2.41E-01	143.5	2.50E-04	64.3	2.15
20	food	Pasta	Aflatoxin B1	Adults (≥ 18 years)	1.79E-04	35.6	4.00E-08	81.2	1.96
21	food	Wheat, bread	ZEA	Adults (≥ 18 years)	2.41E-01	127.9	2.50E-04	81.2	1.52
22	feed	Maize	DON	Piglets	9.69E-01	64.1	1.65E-03	25	1.50
23	food	Breakfast cereals	Aflatoxin B1	Child (4 -12 years)	2.86E-04	5.5	4.00E-08	34.3	1.14
24	feed	Wheat	DON	Fattening pigs	3.92E-01	393.7	1.23E-03	125	1.01
25	food	Wheat, bread	DON	Toddlers (1-3 years)	1.61E-01	81.7	1.00E-03	13.8	0.95
26	feed	Wheat	DON	Beef cattle	3.92E-01	3275.6	1.77E-03	791	0.92
27	food	Maize (products)	Aflatoxin B1	Toddlers (1-3 years)	3.62E-04	1.1	4.00E-08	13.8	0.71
28	feed	Maize	DON	Laying hens	9.69E-01	43.2	2.98E-02	2	0.70
29	feed	Wheat products	DON	Sows	3.50E-01	471.0	1.04E-03	230	0.69
30	food	Breakfast cereals	Aflatoxin B1	Adolescents (13-17 years)	2.86E-04	6.1	4.00E-08	64.3	0.68
31	feed	Barley	DON	Fattening pigs	1.48E-01	634.7	1.23E-03	125	0.61
32	food	Breakfast cereals	Aflatoxin B1	Adults (≥ 18 years)	2.86E-04	6.9	4.00E-08	81.2	0.61
33	feed	Maize	DON	Breeding hens	9.69E-01	48.4	4.03E-02	2	0.58
34	food	Maize (products)	Aflatoxin B1	Child (4 -12 years)	3.62E-04	2.1	4.00E-08	34.3	0.56
35	food	Wheat, bread	DON	Child (4 -12 years)	1.61E-01	115.6	1.00E-03	34.3	0.54
36	feed	Wheat products	DON	Fattening pigs	3.50E-01	233.5	1.23E-03	125	0.53
37	feed	Wheat	DON	Sows	3.92E-01	267.6	1.04E-03	230	0.44
38	feed	Maize	ZEA	Goats	1.65E-01	143.4	2.80E-03	20	0.42
39	feed	Maize	DON	Broilers	9.69E-01	20.4	1.96E-02	2.4	0.42
40	feed	Maize	ZEA	Piglets	1.65E-01	64.1	1.04E-03	25	0.41
41	feed	Wheat	T-2/HT-2 toxin	Broilers	3.39E-02	38.3	1.33E-03	2.4	0.41
42	feed	Maize	DON	Gilts	9.69E-01	60.4	6.97E-04	230	0.37
43	feed	Wheat	T-2/HT-2 toxin	Breeding hens	3.39E-02	28.7	1.33E-03	2	0.37
44	feed	DDGS	DON	Beef cattle	1.50E+00	335.6	1.77E-03	791	0.36
45	food	Wheat, bread	DON	Adolescents (13-17 years)	1.61E-01	143.5	1.00E-03	64.3	0.36
46	feed	Barley	DON	Sows	1.48E-01	577.5	1.04E-03	230	0.36
47	feed	Bakery products	DON	Fattening pigs	2.03E-01	248.9	1.23E-03	125	0.33
48	feed	Barley	DON	Piglets	1.48E-01	91.1	1.65E-03	25	0.33
49	feed	Wheat	DON	Broilers	3.92E-01	38.3	1.96E-02	2.4	0.32
50	feed	Wheat	DON	Piglets	3.92E-01	31.8	1.65E-03	25	0.30

HBGV: Health Based Guidance Value; RPHC: Reference Point for potential Health Concern; HQ: hazard Quotient; DON: deoxynivalenol; ZEA: zearalenone.

For the scoring and risk ratio method, the total amount of feed used in the Netherlands was derived from SecureFeed, a feed industry organisation collecting data from the feed industry which represents 80% of the compound feed produced in the Netherlands (Van der Fels-Klerx et al., 2017). The total amount of feed used in the Netherlands was derived for the year 2019, and corrected for the proportion used in compound feed. The portion of feed ingredients per animal category was obtained with a feed optimization program, as described by Van der Fels-Klerx et al. (2017). For the risk ratio method, the usage per feed material was multiplied with the proportion of the feed material per

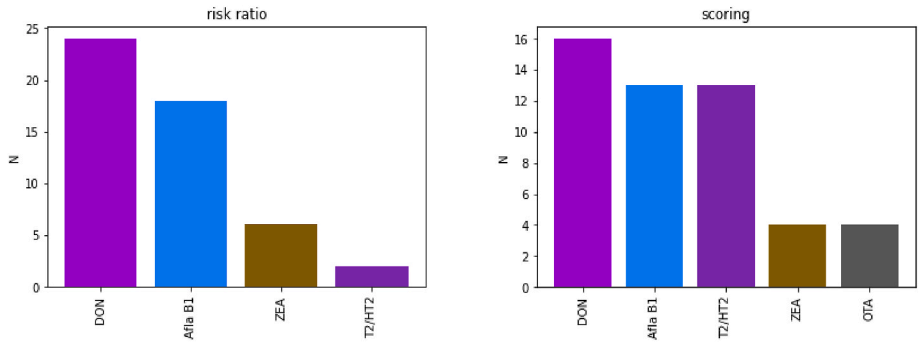

Fig. 1. Number of chemical hazards ranked in the top 50 for the risk ratio method (a) and the scoring method (b).

animal category. This total consumption was divided by 365 days and the number of animals of that species in the Netherlands. This resulted in a consumption per feed material and species in g/day.

Data related to the portion of feed and food imported to the Netherlands and the production in the Netherlands (factor c in the scoring method) were retrieved from Eurostat (2021) and CBS (2022b), respectively, for the year 2019.

2.3.2. Concentration data

For food and feed, data on the concentration of the studied contaminants were obtained from the National monitoring plan of animal feed, which is submitted to the KAP (Quality Agricultural Products) database that is hosted by the National Institute for Public Health and the Environment (KAP, 2021). This database contains samples originating from the Netherlands as well as data for imported products from outside the Netherlands. For the risk ratio method, data were retrieved for the considered contaminants and feed and food material in the period 2012–2016, similar to the time period of the most recent food consumption data. For the scoring method, KAP data from a previous study were used, which focused on the period 2014–2018. The concentration data from KAP were averaged per contaminant and feed or food combination.

2.3.3. Health effects

Both the effect on humans and animals were considered in the risk ranking. For human health effects, HBGVs or RPHCs were used based on opinions of the European Food Safety Authority (EFSA). For cadmium, DON, T-2/HT-2 toxin and ZEA, established tolerable daily intakes (TDIs) or weekly intakes (TWIs) were used (EFSA, 2009, 2016; EFSA et al., 2017a; 2017b). For lead, aflatoxin B1 and OTA available benchmark dose levels (BMDLs) were used (EFSA, 2010, 2020; EFSA et al., 2020) taking into account a Margin Of Exposure of 10.000 to obtain a RPHC value. More detailed information is available in Hobé et al. (2023). For animal health, NOAELs were derived. For this purpose, available EFSA reports were used (EFSA, 2004a; 2004b, 2014, 2020; EFSA et al., 2017c) and several assumptions were made in case of a lack of data. In case only Low Observed Adverse Effect Levels (LOAELs) were available, an uncertainty factor of 3 to derive the NOAEL was used analogous to EFSA (EFSA, 2020). Furthermore, NOAELs were divided by ten to account for interspecies variability, which can be seen as a worst case assumption. For aflatoxin B1, no NOAELs were available for the various animal species. As an assumption, the action limits in feed were used as established by the US FDA (US FDA, 2000). For ZEA, no data were available for cows. However, cows are, like chicken, not very sensitive to ZEA and, therefore, the NOAEL for chicken was used as assumption (EFSA et al., 2017b). For OTA, a LOAEL was available for pigs of 8 μg/kg bw/day. Since chicken are equally sensitive to OTA as pigs, the same LOAEL was used for this animal species (EFSA, 2020). Ruminants are less sensitive to OTA than pigs and chicken and - analogous to the scores used for this hazard in RiskFeed (Van der Fels-Klerx et al., 2017) - the LOAEL was assumed to be a factor 100 higher than for pigs and chicken. For Pb, a sub-clinical dose of 4.5 mg/kg dry matter (comparable to 3.96 mg/kg feed assuming 12% moisture content) resulted in a decreased learning ability (EFSA, 2004). As a worst case assumption, it was assumed that these effects were relevant for all young animals and animals that produce offspring (i.e. piglets, gilts, dairy cows, young cows, veal, sheep and goat). The level of 3.96 mg/kg feed was therefore used as LOAEL for the specified animal species. For chicken, a NOAEL of 1 mg/kg feed was applied as established by Bakalli et al. (1995). In case NOAELs were available in mg/kg feed, these were converted into mg/kg bw/day by multiplying with the daily consumption of the animal species and dividing by its body weight.

For the scoring method, the health effects were incorporated in the consequence factor e. In case no maximum limit or guidance value was available for the chemical hazard studied, a value of 0.001 was set. For all other cases, the classification was performed by experts based on available data and scientific literature with respect to potential transfer and accumulation, estimated daily intakes and toxic effects of the contaminant on animal and human. This allowed the inclusion of differences in sensitivity between animal species and human age groups. For feed, the consequence factor e_animal was used as described by Van der Fels-Klerx et al. (2017). For food, the consequence factor e_{human} was used, as described below.

For the classification into low, medium and high the daily intake was estimated using the high-end consumption as established by EFSA based on the Dutch National Food Consumption Survey 2012–2016 (EFSA, 2021) and multiplying thiswith the mean occurrence of chemical hazards between 2014 and 2018 from the KAP database (KAP, 2021). This value was divided by the body weight of adults, adolescents, children, and toddlers. The outcome was divided by the HBGV or RPHC. Analogous to the RiskFeed model, the consequence factor was assumed to be 1 when the ratio was above 0.5. For a ratio between 0.2 and 0.5, the consequence factor was assumed to be 0.1. If the ratio was below 0.2, then the consequence factor was assumed to be 0.01.

3. Results

3.1. Risk ratio method

Using the risk ratio method, a total of 280 hazard-food-human group combinations as well as 1729 hazard-feed-animal groups were ranked. Table 1 presents the results of the top 50 highest hazard-product combinations per animal or human group. This Table shows that the mycotoxins ranked higher than the heavy metals as the highest ranked heavy metal, i.e. cadmium in wheat bread for toddlers, was found at place 60, which can be partly explained by the low RPHC. Overall, DON was most frequently found in the top 50 (n = 24), followed by aflatoxin B1 (n = 18), ZEA (n = 6) and T2/HT2 (n = 2) (see Fig. 1). Aflatoxin B1 and ZEA were ranked highest in food products, whereas DON was primarily ranked high in feed. The latter was caused by the low NOAELs for

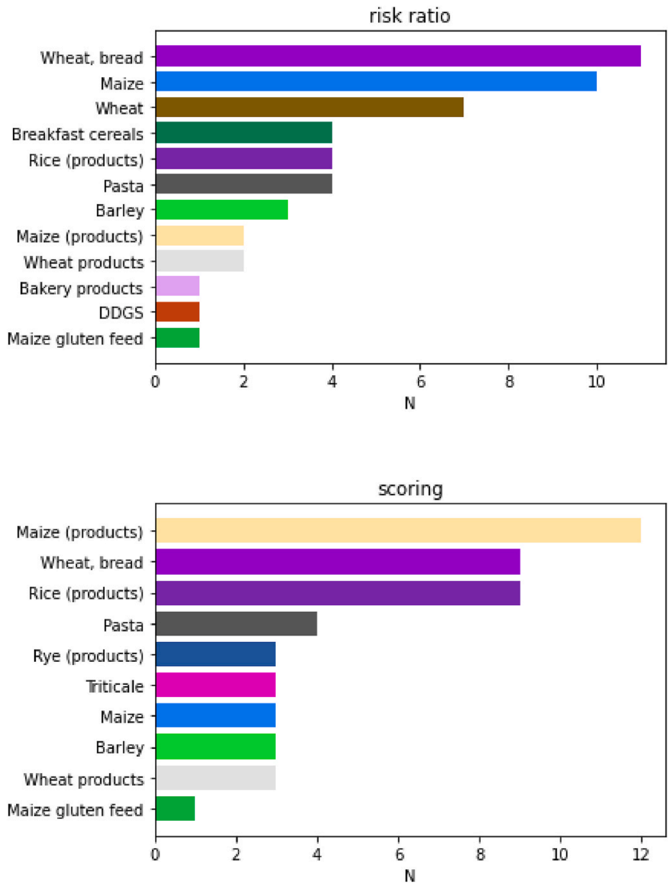

Fig. 2. Number of products ranked in the top 50 for the risk ratio method (a) and the scoring method (b); DDGS: dried distillers grains with solubles.

some animal species in combination with high DON concentrations found in feed as compared to the other mycotoxins. Maize and wheat products were most frequently included in the top 50 products, either intended for feed or food (see Fig. 2). These products contained the highest levels of mycotoxins compared to the other cereals. Evaluating the different age groups for humans showed that children and toddlers were most frequently found in the top 50 (each 7 times) followed by adolescents and adults (6 and 5 times, respectively). For the feed products, pigs were most frequently ranked in the top 50 (14 times), followed by chicken (5 times), cows (4 times) and goat (once) (see Fig. 3). Amongst all animal species, sheep were ranked lowest implying feed products for sheep are less relevant to include in monitoring.

3.2. Scoring method

For the scoring method, the same hazard-food-human and hazard-feed-animal combinations were ranked. Table 2 provides an overview of the hazard-product combinations ranked in the top 50 for different animal or human groups. Like the risk ratio method, overall, mycotoxins ranked higher than the heavy metals. The highest ranked heavy metal again was cadmium, which was ranked at place 119 for bakery products consumed by fattening pigs. Table 2 shows that food was more frequently included in the top 50 than feed products. Like with the risk ratio method, maize- and wheat-based products were most frequently included in the top 50 (see also Fig. 2). In contrast to the risk ratio method, rice was more frequently included (n = 9). Highest scores were found for aflatoxins, DON and T2/HT2. DON was most frequently found (n = 16) followed by aflatoxins and T2/HT2 (both 13 times) in the top 50 (Table 2 and Fig. 1). These mycotoxins ranked high since their consequence factor (factor e) was evaluated equally high for humans, i.e. e = 1. When comparing the different age groups, adults were most frequently included in the top 50 (n = 13) followed by adolescents (n = 11), children (n = 7) and toddlers (n = 6). Furthermore, the scoring method also shows that fattening pigs frequently obtained a high score (n = 12) (see Fig. 3).

3.3. Comparison between risk ratio and scoring method

The risk ratio and scoring method both use information on concentration, consumption and toxicity as input for the ranking. When comparing Tables 1 and 2 as well as the outcomes of the two ranking methods in Figs. 1–3, some apparent differences can be seen.

The differences between the methods can best be explored using two examples. In the first example, the results obtained for DON in barley and maize intended for fattening pigs were compared (see Table 3). Since the same chemical hazards and target animal are used in this example, the health effect (NOAEL for the risk ratio method and factor e in the risk scoring method) can be ignored in the sense that they do not influence the difference in outcomes between the two examples. The risk ratio method shows an average DON concentration of 148 μg/kg in barley and of 969 μg/kg in maize, i.e. the DON concentration is 6 times higher in maize than in barley. The DON concentration in the risk scoring method is reflected in the factor d, which is both 0.1 for barley and maize. This factor is based on the percentage of samples above the ML, the average concentration divided by the ML as well as expert judgment. All these factors were evaluated equally for barley and maize. The difference between maize and barley in the scoring method can thus only be explained by a difference in consumption (factor a*b), which is 0.46 for barley and 0.24 for maize, i.e. around a factor 2 lower for maize. In contrast, the consumption per day as calculated in the risk ratio method is comparable for both barley and maize (635 and 587 g/day,

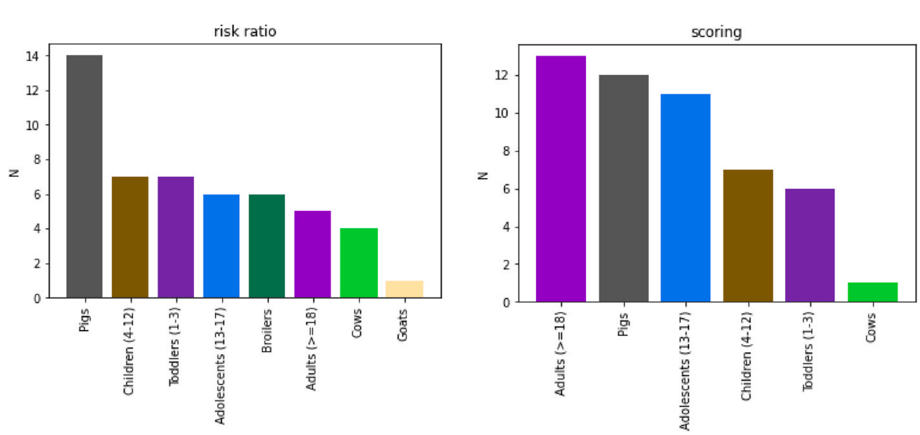

Fig. 3. Number of times a human or animal group was ranked in the top 50 for the risk ratio method (a) and the scoring method (b).

Table 2
Top 50 for ranking food and feed using the scoring method.

Rank	Product type	Product	Chemical hazard	Group	a log/log(total)	a*b	c*d	e	Final score
1	FOOD	Wheat, bread	DON	Adolescents (13-17 years)	0.9557	0.2926	0.9540	1.0000	0.2791
2	FOOD	Rice (products)	Aflatoxin B1	Adults (≥ 18 years)	0.6886	0.2786	1.0000	1.0000	0.2786
3	FOOD	Rice (products)	T-2/HT-2 toxin	Adults (≥ 18 years)	0.6886	0.2786	1.0000	1.0000	0.2786
4	FOOD	Wheat, bread	DON	Adults (≥ 18 years)	0.9557	0.2608	0.9540	1.0000	0.2488
5	FOOD	Wheat, bread	DON	Child (4-12 years)	0.9557	0.2357	0.9540	1.0000	0.2248
6	FOOD	Rice (products)	Aflatoxin B1	Adolescents (13-17 years)	0.6886	0.1749	1.0000	1.0000	0.1749
7	FOOD	Rice (products)	T-2/HT-2 toxin	Adolescents (13-17 years)	0.6886	0.1749	1.0000	1.0000	0.1749
8	FOOD	Wheat, bread	DON	Toddlers (1-3 years)	0.9557	0.1667	0.9540	1.0000	0.1590
9	FOOD	Rice (products)	Aflatoxin B1	Child (4-12 years)	0.6886	0.1549	1.0000	1.0000	0.1549
10	FOOD	Rice (products)	T-2/HT-2 toxin	Child (4-12 years)	0.6886	0.1549	1.0000	1.0000	0.1549
11	FOOD	Maize (products)	Aflatoxin B1	Adults (≥ 18 years)	0.4550	0.1428	0.8981	1.0000	0.1282
12	FOOD	Maize (products)	DON	Adults (≥ 18 years)	0.4550	0.1428	0.8981	1.0000	0.1282
13	FOOD	Maize (products)	T-2/HT-2 toxin	Adults (≥ 18 years)	0.4550	0.1428	0.8981	1.0000	0.1282
14	FOOD	Maize (products)	AFLATOXINE B1	Child (4-12 years)	0.4550	0.1390	0.8981	1.0000	0.1248
15	FOOD	Maize (products)	DON	Child (4-12 years)	0.4550	0.1390	0.8981	1.0000	0.1248
16	FOOD	Maize (products)	T-2/HT-2 toxin	Child (4-12 years)	0.4550	0.1390	0.8981	1.0000	0.1248
17	FOOD	Maize (products)	Aflatoxin B1	Adolescents (13-17 years)	0.4550	0.1027	0.8981	1.0000	0.0922
18	FOOD	Maize (products)	DON	Adolescents (13-17 years)	0.4550	0.1027	0.8981	1.0000	0.0922
19	FOOD	Maize (products)	T-2/HT-2 toxin	Adolescents (13-17 years)	0.4550	0.1027	0.8981	1.0000	0.0922
20	FOOD	Rice (products)	Aflatoxin B1	Toddlers (1-3 years)	0.6886	0.0802	1.0000	1.0000	0.0802
21	FOOD	Rice (products)	T-2/HT-2 toxin	Toddlers (1-3 years)	0.6886	0.0802	1.0000	1.0000	0.0802
22	FOOD	Maize (products)	Aflatoxin B1	Toddlers (1-3 years)	0.4550	0.0706	0.8981	1.0000	0.0634
23	FOOD	Maize (products)	DON	Toddlers (1-3 years)	0.4550	0.0706	0.8981	1.0000	0.0634
24	FOOD	Maize (products)	T-2/HT-2 toxin	Toddlers (1-3 years)	0.4550	0.0706	0.8981	1.0000	0.0634
25	FEED	Barley	DON	Fattening pigs	0.8126	0.4603	0.0906	1.0000	0.0417
26	FEED	Barley	Ochratoxin A	Fattening pigs	0.8126	0.4603	0.0906	1.0000	0.0417
27	FEED	Barley	ZEA	Fattening pigs	0.8126	0.4603	0.0906	1.0000	0.0417
28	FEED	Wheat products	DON	Fattening pigs	0.7025	0.3949	0.0918	1.0000	0.0362
29	FEED	Wheat products	Ochratoxin A	Fattening pigs	0.7025	0.3949	0.0918	1.0000	0.0362
30	FEED	Wheat products	ZEA	Fattening pigs	0.7025	0.3949	0.0918	1.0000	0.0362
31	FOOD	Wheat, bread	T-2/HT-2 toxin	Adolescents (13-17 years)	0.9557	0.2926	0.0991	1.0000	0.0290
32	FOOD	Wheat, bread	Aflatoxin B1	Adolescents (13-17 years)	0.9557	0.2926	0.0958	1.0000	0.0280
33	FOOD	Rice (products)	DON	Adults (≥ 18 years)	0.6886	0.2786	0.1000	1.0000	0.0279
34	FEED	Triticale	DON	Fattening pigs	0.4548	0.2976	0.0919	1.0000	0.0273
35	FEED	Triticale	Ochratoxin A	Fattening pigs	0.4548	0.2976	0.0919	1.0000	0.0273
36	FEED	Triticale	ZEA	Fattening pigs	0.4548	0.2976	0.0919	1.0000	0.0273
37	FOOD	Pasta	Aflatoxin B1	Adolescents (13-17 years)	0.7969	0.2765	0.0982	1.0000	0.0272
38	FOOD	Pasta	DON	Adolescents (13-17 years)	0.7969	0.2765	0.0982	1.0000	0.0272
39	FOOD	Pasta	T-2/HT-2 toxin	Adolescents (13-17 years)	0.7969	0.2765	0.0982	1.0000	0.0272
40	FOOD	Rye (products)	Aflatoxin B1	Adults (≥ 18 years)	0.3806	0.2599	0.1000	1.0000	0.0260
41	FOOD	Wheat, bread	T-2/HT-2 toxin	Adults (≥ 18 years)	0.9557	0.2608	0.0991	1.0000	0.0258
42	FOOD	Wheat, bread	Aflatoxin B1	Adults (≥ 18 years)	0.9557	0.2608	0.0958	1.0000	0.0250
43	FOOD	Rye (products)	DON	Adults (≥ 18 years)	0.3806	0.2599	0.0958	1.0000	0.0249
44	FOOD	Rye (products)	T-2/HT-2 toxin	Adults (≥ 18 years)	0.3806	0.2599	0.0958	1.0000	0.0249
45	FEED	Maize	DON	Fattening pigs	0.8859	0.2395	0.1000	1.0000	0.0239
46	FEED	Maize	Ochratoxin A	Fattening pigs	0.8859	0.2395	0.1000	1.0000	0.0239
47	FEED	Maize	ZEA	Fattening pigs	0.8859	0.2395	0.0982	1.0000	0.0235
48	FOOD	Wheat, bread	T-2/HT-2 toxin	Child (4-12 years)	0.9557	0.2357	0.0991	1.0000	0.0233
49	FEED	Maize gluten feed	DON	Dairy cows	0.4649	0.2325	1.0000	0.1000	0.0233
50	FOOD	Pasta	Aflatoxin B1	Adults (≥ 18 years)	0.7969	0.2356	0.0982	1.0000	0.0231

a: total amount of feed or food used in the Netherlands (kton/year); b: portion of feed ingredient per animal category or portion of food product per human age group (%); c: portion of feed or food product imported per country (%); 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; DON: deoxynivalenol, ZEA: zearalenone.

respectively). The difference between maize and barley in the risk ratio method, thus, primarily depends on the difference in the DON concentrations found in maize and barley. Since the underlying data for both models are comparable for the concentration and consumption data, this example shows that the way these data were subsequently computed to derive factor a*b as indication for consumption and the classifications used for factor d as indication for concentration impacts the outcome.

Another example explored was the differences found for the age groups in humans with younger age groups more frequently included in the risk ratio method whereas the older age groups dominated the scoring method. The results obtained for the two methods for aflatoxin B1 in wheat were compared for adults and toddlers. This showed that with a comparable HBGV (4.0E-8 for the risk ratio method and factor e = 1 for the scoring method), adults obtain a lower rank in the risk ratio method compared to the scoring method. In the risk ratio method, the average bodyweight of the age group is taken into account, which allows for a lower exposure for toddlers compared to adults. This factor is not included in the scoring method. Since adults have a higher consumption than toddlers, this age group then obtains a higher final score in the scoring method and thus a higher rank than toddlers (Table 3).

A difference between the risk ratio and the scoring method is that the latter allows for the inclusion of country of origin as this is incorporated in factor c. In the risk ratio method this is not included. A ranking per country is possible with this method for the top hazard-product combinations using the weighted import, i.e. the import volume multiplied with the country risk as explained in Hobé et al. (2023). For the risk ratio method, an additional step is thus needed to allow for a ranking per country.

4. Discussion

The aim of this study was to determine whether a method was

Table 3
Comparison between the risk ratio and scoring method for two examples.

Example 1. Comparison between DON in barley and maize used for fattening pigs										
Risk ratio method										
Product	Hazard	Group	Concentration (mg/kg)	Consumption (g/day)	EDI (mg/day)	NOAEL (mg/kg bw/day)	Weight (kg)		HQ	Rank
Barley (feed)	DON	Fattening pigs	0.148	634.7	0.094	0.0012	125		0.61	31
Maize (feed)	DON	Fattening pigs	0.969	586.5	0.568	0.0012	125		3.71	12
Risk scoring method										
Product	Hazard	Group	Use in NL (kton/year)	a (log use/log total use)	b (% to pigs)	a*b	c (% per country) *d (score per country)	e (severity)	Final score (a*b*c*d*e)	Rank
Barley (feed)	DON	Fattening pigs	1521	0.81	56.6%	0.46	0.09	1.0	0.0417	25
Maize (feed)	DON	Fattening pigs	2945	0.89	27.0%	0.24	0.10	1.0	0.0239	45
Example 2. Comparison between adults and toddlers for aflatoxin B1 in wheat										
Risk ratio method										
Product	Hazard	Group	Concentration (mg/kg)	Consumption (g/day)	EDI (mg/day)	NOAEL (mg/kg bw/day)	Weight (kg)		HQ	
Wheat, bread	Afla B1	Toddlers	0.0004	81.7	2.88E-5	4.0E-8	13.8		52.3	1
Wheat, bread	Afla B1	Adults	0.0004	127.9	4.51E-5	4.0E-8	81.2		13.9	7
Risk scoring method										
Product	hazard	Group	Consumption (kton/year)	A (log use/log total use)	B (% to pigs)	A*B	C (% per country) *D (score per country)	E (severity)	Final score (a*b*c*d*e)	
Wheat, bread	Afla B1	Toddlers	3028	0.96	17.4%	0.167	0.096	1.0	0.016	83
Wheat, bread	Afla B1	Adults	3028	0.96	27.3%	0.261	0.096	1.0	0.025	42

available to rank chemical hazards in food and feed simultaneously. Two methods, i.e. a scoring method and a risk ratio method were used for this purpose and compared for prioritizing chemical hazards in food and feed. The results of our study showed that both methods were capable of ranking hazard-product combinations considering both feed and food. Comparison between the two methods showed similarities and differences that are further discussed in this section. Both methods showed that mycotoxins are more relevant than heavy metals in cereals and maize and wheat were the most relevant cereals to include in monitoring. It should be noted that the prioritization performed using the two methods is based on average values. Mycotoxins are known to be heterogeneously present and thus incidental high levels may be found. In our prioritization, we compared the daily intake to chronic adverse effects making the use of average values more appropriate. For expected worst-case situations, specific surveys can be conducted as addition to a risk-based monitoring program allowing to estimate potential human health risks for incidental cases. Although cereals have a large contribution to the human intake of, for example, cadmium, levels found in these products are usually low compared to animal-based products. This is in line EFSA who concludes that the high contribution of cereals to the total cadmium intake is primarily attributed to the high cereal consumption levels and not to high concentrations in cereals (EFSA, 2012). Mycotoxins are more frequently found in cereals. Cheli et al. (2021) recently reviewed mycotoxin contamination of cereals in Europe and showed that fumonisins and DON were most frequently reported. In our study, fumonisins were not included, but indeed DON was found most frequently in the top 50 ranked hazard-food combinations. The type of mycotoxin occurring in cereals heavily depends on regional climatic circumstances with a high likelihood of finding fumonisins and aflatoxins in warmer regions, such as South Asia and ZEA and DON in colder areas, such as North Asia and North America (Schatzmayr & Streit, 2013). Climate change is expected to change the occurrence of mycotoxins in various parts of the world (Paterson & Lima, 2010). Comparing the results for the different human age groups showed that both methods retrieved different outcomes, with the risk ratio method resulting in a higher ranking of products consumed by the young age groups than with the scoring method. Younger people are more vulnerable than adults and products intended for younger people are thus expected to end up higher in the ranking. For example, the EFSA opinion on aflatoxins indicated that the chronic dietary exposure to aflatoxins is estimated to be higher for the young population groups (EFSA et al., 2020). The high daily intake relative to their body weight results in a higher risk for these age groups. The prioritization per age group can be used to select food products for monitoring. For example, aflatoxin B1 scores high in both ranking methods. Rice products are identified as high risk products for this food safety hazards. When younger age groups rank higher than adults, products specific for young people may be selected as part of the monitoring program. In this case for example rice crackers could be selected since they are highly consumed by toddlers and young children rather than rice itself which is more consumed by adults.

Considering the different animal groups, both methods resulted in highest ranks for pigs. This is due to the presence of DON in cereals, the cereal consumption by pigs and their sensitivity to DON. EFSA established the lowest NOAEL for pigs as compared to other livestock animals (EFSA et al., 2017a,b,c).

Many methods are available to prioritize chemical hazards and depending on the goal and available time and budget, one of these methods can be selected to rank hazard-product combinations (Van der Fels-Klerx et al., 2018). In this study two of these methods were compared: a semi-quantitative method (the scoring method) and a quantitative method (risk ratio method). As indicated previously, each risk ranking method has its pros and cons (Van der Fels-Klerx et al., 2018), which was also seen in the current study. The scoring method can easily be applied and requires less data than the risk ratio method. Furthermore, expert opinion can be added as is included in the contamination factor (factor d). The method includes both continuous (factors a-c) and discrete (factors d-e) variables. The downside of this method is that thresholds need to be established to set the different classes (low, medium or high) for these discrete variables and these thresholds showed to influence the outcome of the classification as shown in the examples explained in section 3.3. The risk ratio method uses a continuous scale for all parameters and, as such, a more accurate estimation of the prioritization can be achieved. The downside of this method is that many data are needed and sometimes assumptions had to be made due to a lack of data. For example, the NOAELs were not available for all animal species so assumptions had to be made to derive these for the various species. However, also for the consequence factor (factor e) in the scoring method, the same assumptions had to be made. This consequence factor includes not only the direct health effects of cereals on animals and humans but also the indirect effect of hazards on humans via transfer from cereals into animal products due to bioaccumulation. As such, it is a broader factor then the direct health effects included in the risk ratio method.

5. Conclusion

Results showed that the mycotoxins deoxynivalenol, aflatoxin B1 and zearalenone were ranked highest in both methods. Maize and wheat products were most frequently included in the top 50 ranked hazard-food combinations. Although both methods were capable of ranking hazard-product combinations for various animal or human groups, differences between the methods were observed. When enough data is available on concentration, consumption and toxicity, the risk ratio method showed to give a more accurate prioritization. Nevertheless, depending on available data and risk manager preferences, the risk scoring method may be preferred as it allows more flexibility in including both data and expert judgment, in case of limited data availability, and allows for the inclusion of country of origin, which is relevant for imported products. Although the methodologies were tested in a case study on mycotoxins and heavy metals in cereals, they are capable of ranking other hazard-product combinations and thus can be expanded to a broader range of chemical hazards and food and feed products. It is recommended to verify this by exploring other case studies focusing on other chemical hazards, other products and other regions. Since the methods described can rank food and feed products simultaneously, food safety authorities can use them to divide the available monitoring resources according to the highest expected risks. As such, the outcome can be used as input to establish a risk-based monitoring program for food and feed.

CRediT authorship contribution statement

E.D. van Asselt: Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Supervision. **R.G. Hobé:** Conceptualization, Methodology, Data curation, Software, Investigation, Visualization, Writing – original draft. **E.F. Hoek-van den Hil:** Conceptualization, Methodology, Investigation, Writing – review & editing. **H.J. van der Fels-Klerx:** Conceptualization, Methodology, Supervision, Project administration, Funding acquisition, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Esther van Asselt reports financial support was provided by Dutch Ministry of Agriculture, Nature and Food Quality.

Data availability

Data will be made available on request.

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