World Mycotoxin Journal, May 2009; 2 (2): 119-127

Wageningen Academic Publishers

Development of a European system for identification of emerging mycotoxins in wheat supply chains

H.J. van der Fels-Klerx[1], M.C. Kandhai[1], S. Brynestad[2], M. Dreyer[3], T. Börjesson[4], H.M. Martins[5], M. Uiterwijk[6], E. Morrison[2] and C.J.H. Booij[7]

[1]RIKILT, Institute of Food Safety, Wageningen UR, P.O. Box 230, 6700 AE Wageningen, the Netherlands; [2]Det Norske Veritas, Veritasveien 1, 1322 Høvik, Norway; [3]DIALOGIK, Lerchenstrasse 22, 70176 Germany; [4]Lantmannen, Business Development Grain, 531 87, Lidköping, Sweden; [5] INRB, I.P.-Laboratório Nacional de Investigação Veterinária, Estrada de Benfica 701, 1549-011 Lisboa, Portugal; [6]Alterra, Wageningen UR, P.O. Box 47, 6700 AA Wageningen, the Netherlands; [7]Plant Research International, Wageningen UR, P.O. Box 16, 6700 AA Wageningen, the Netherlands; ine.vanderfels@wur.nl

Received: 28 November 2008 / Accepted: 23 February 2009

Abstract

This paper describes the results of a research project aimed at the conceptual development of an identification system for emerging mycotoxins in European feed and food supply chains of wheat. Basic requirements for such a system were addressed, including the selection of indicators, locating information sources, development of underlying model, and investigation of stakeholders' needs. The selection and ranking of key indicators for identifying emerging mycotoxins was based on a literature review, followed by a structured expert judgment study. The expert study was based on the Delphi technique and used a panel of 43 European experts. The Delphi procedure resulted in a selected set of 12 key indicators for each of three relevant stages of the wheat chain (cultivation; transport and storage; processing). For wheat cultivation, these were: relative humidity/rainfall, crop rotation, temperature, tillage practice, water activity in the kernels, crop variety, harvest conditions, changes in fungal populations, fungicide use, plant health, regional infection pressure and food safety awareness. For the majority of the selected indicators, information sources were identified in specific European countries. However, most sources are not readily accessible and particular data is lacking. A theoretical concept for a model underlying the envisioned emerging mycotoxin identification system has been developed. The model links the key indicators and their information sources to aid and promote identification of emerging mycotoxins. It manages different types of information sources and levels of available information. The needs of various stakeholder groups regarding the system were investigated by means of two empirical elicitation sessions. The results showed that all stakeholders considered that such a system would be beneficial. One major challenge expected in establishing the system is stakeholder commitment to sharing data and information. This requires great efforts in improving communication and interaction between the key stakeholders.

Keywords: emerging hazards, indicators, expert judgement, *Fusarium*, modelling

1. Introduction

Regulation (EC) No. 178/2002 ('General Food Law') led to the establishment of the European Food Safety Authority (EFSA), including the mandate to set up a pan-European system for the identification and evaluation of emerging risks. Specifically, EFSA should 'establish monitoring procedures for systematically searching for, collecting, collating and analyzing information and data with a view to the identification of emerging risks in the fields within its mission' (EC, 2002). An emerging risk to human or animal health is defined as a risk resulting from a newly identified hazard to which a significant exposure may occur, or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard (it is then called re-emerging risk) (EFSA, 2007). For managing emerging risks, a system or procedure that proactively identifies potential emerging hazards is an essential feature. Only the timely recognition of an emerging hazard will provide risk managers with the opportunity to prevent the hazard from actually becoming a risk. The system for identifying emerging hazards will mainly be based on indicators, which are factors that signal for the possibility of the occurrence of an emerging hazard (newly identified hazard or increased occurrence of known hazard), often when exceeding a certain threshold level. Following the holistic approach, conceptualised in the European projects PERIAPT (Noteborn and Ooms, 2005) and EMRISK (Noteborn, 2006) and elaborated upon in SAFE FOODS (Dekkers *et al.*, 2008; Kleter and Marvin, 2009; Marvin *et al.*, 2009a,b), the identification of emerging hazards starts with a host environmental analysis of the feed and/or food supply chain of interest. This approach implies investigation of the chain and its influential sectors, i.e. sectors directly or indirectly related to the particular feed/food chain, with the aim to select measurable indicators to be included and monitored in an emerging hazard identification system. More information on the holistic approach can be found in the references cited above.

Because evaluation and validation of the importance of indicators for each potential emerging hazard is resource intensive and time consuming, EFSA was advised by the Scientific Committee to limit its vigilance to key areas and concentrate on the identification and validation of relevant indicators for these areas (EFSA, 2006). One of these key areas is emerging mycotoxin related hazards due to ubiquity of toxins and the degree of knowledge and competence regarding these hazards. The occurrence and risks of a number of mycotoxins are well known and documented. Known mycotoxins are included in management and control systems such as Hazard Analysis and Critical Control Points (HACCP) and notification systems like the Rapid Alert System for Food and Feed (RASFF) (see e.g. EC, 2007). For some mycotoxins, such as deoxynivalenol and zearalenone in wheat, even predictive models are available (e.g. Hooker *et al.*, 2002; Rossi *et al.*, 2003; Schaafsma and Hooker, 2007; Prandini *et al.*, 2009). It is clear, however, that there are a number of mycotoxins that either have a low incidence or are unknown that may (re-)emerge or be (re-)introduced into the food chain, e.g. as a result of effects arising from climate change, global trade and technological changes in the processing industries (Beyer *et al.*, 2007; Magan and Aldred, 2007). The formation of new toxins is only discovered through improvement of detection and analytical tools (e.g. Jestoi *et al.*, 2004; Sulyok *et al.*, 2007), and indicators for their occurrence are currently poorly understood. Therefore, in addition to the current systems for mycotoxin risk management, there is a need for a proactive approach to the identification of emerging mycotoxins.

The aim of this project was to develop a systematic approach to identify emerging mycotoxins (EM), particularly related to *Fusarium* spp., in European wheat-based feed and food supply chains. The main aim of the research was broken down into the following four objectives:

- Selection and ranking of the most important indicators for EM occurrence.
- Identification of the most relevant information sources for the selected key indicators.
- Development of an information model to link information sources on the selected key indicators, and evaluation of applicability of such a model.
- Identification of information format and content for effective utilisation of the EM identification system, as perceived by different groups of stakeholders.

This project addressed the basic elements for developing an identification system for one of the main feed and food safety hazards in the European Union. As such it directly contributes to EFSA needs regarding emerging risk identification. Although the research addresses a specific group of emerging hazards, the results and experiences will contribute to future initiatives regarding identification systems for comparable emerging hazards in feed and food chains.

2. Material and methods

Selection of indicators

In selecting the most important indicators for EM identification, a literature study and expert judgment were used. Prioritisation and consensus was reached by applying the Delphi technique to a panel of 43 European experts. The Delphi technique enables group interaction in an anonymous setting thereby avoiding the effect of expert dominance (Van der Fels-Klerx *et al.*, 2000). It facilitates the simultaneous solicitation and analysis of expert opinions and can be used to evaluate a large number of factors with the aim of prioritising and restricting the queried set of factors.

In this research, the specific aim was to select the most important indicators for identification of emerging mycotoxins, particularly related to *Fusarium* spp., in wheat-based feed and food supply chains. The Delphi technique was applied to evaluate and rank a wide range of indicators from various influential sectors, and to reach consensus on the most important indicators, per supply chain stage (cultivation; transport and storage; processing). Design and results of the Delphi expert study are summarised below.

Initially, an extensive list of potential indicators per supply chain stage was established, based on a literature review (full list presented in Van der Fels-Klerx *et al.*, 2008) and later reduced by combining related indicators. In the first

Delphi round this list was distributed to the individual experts, and comprised 41 indicators for the cultivation stage, 26 indicators for the transport and storage stage, and 34 indicators for the processing stage. Experts were asked to evaluate each indicator for relevance for EM identification, add any missing indicators, and to select and rank the ten most important indicators for each chain stage. Ranking was performed by assigning scores ranging from one (least important) to ten (most important). The expert scores were analysed statistically (total score, mean, median, etc.) for selection of indicators to forward to the second round. In the second Delphi round, the resulting prioritised list of indicators for each stage was distributed, excluding information regarding relative ranking, together with the additional indicators mentioned. In this second iteration, again, the ten most important indicators were selected and ranked by each expert for relative importance. Based on these ranking results, the experts in the third Delphi round were presented with a prioritised list of 12 key indicators for each chain stage and asked to rank these relatively by assigning scores. All correspondence was by e-mail.

Identification of information sources

Once the key indicators were selected, sources of information on these indicators were searched for at the European level and specifically also in Portugal, Sweden and the Netherlands, and evaluated for accessibility. Information sources were identified by consulting the expert network from research, farmer organisations, processing industries, and food safety authorities. In addition, library and web searches were applied.

Development of information model

Information sources on the key indicators for EM identification were expected to be diverse in type of information (quantitative versus qualitative), precision of available information, certainty and relevance for EM identification. An EM identification system must be able to handle these various characteristics, while using as much of the available information as possible on the key indicators. A theoretical generic model has been developed for use as a basis for an EM identification system (Van der Fels-Klerx *et al.*, 2008). The model manages both the variety in the nature of the indicators and level of detail of the information available (in space and time). Model development started from results of previous and current studies, including quantitative predictive models for known mycotoxins during wheat cultivation, such as described by Hooker *et al.* (2002) and Franz *et al.* (RIKILT, the Netherlands, unpublished data), and more semi-quantitative and qualitative approaches, like FusaProg (Forrer *et al.*, 2006). In the approach chosen, quantitative modelling is expanded with additional (semi-)qualitative indicators and subsequent stages of the wheat supply chain. In refining the initial theoretical model, matching EM modelling (as part EM identification) with current practices was emphasised.

Investigation of stakeholders' needs

In the development of an EM identification system, customer needs and demands must be mapped with regard to drivers for the user application and type and format of information to the user. Both the aims and conditions may vary among different groups of users. Two key stakeholder groups were distinguished including (a) public authorities involved in feed/food risk assessment and/or management and (b) economic actors of the European wheat feed/food supply chain. Two sessions were held for each stakeholder group; a workshop with group interaction and a series of in-depth bilateral interviews. Both sessions aimed at retrieving information from the expert views on the following four aspects:

- Current practices for managing (emerging) mycotoxins in wheat-based feed and food supply chains.
- Possible add-on functionality of the envisioned EM identification system.
- Information that could be made available to the system.
- Basic information needs and requirements for such a system to be practical.

A one-day workshop was held in the Netherlands and attended by 14 invitees from the Netherlands and Belgium. During this workshop, scenario-based group discussions were held in order to get information on the four aspects from potential users of the system. Two subgroups were formed: one included representatives of public authorities and research institutes (nine persons), the other economic actors were related to wheat-based feed and/or the food industry (five persons). In each subgroup, two identical predefined scenarios were discussed, exemplifying situations of changing conditions potentially affecting the presence of EM in wheat. After the workshop, a series of individual in-depth interviews were held in five European countries (Sweden, Norway, Finland, Denmark and Germany). In total thirteen structured interviews were conducted: five with public authorities responsible for food/feed risk management and assessment, and eight with representatives of feed and food companies (six persons) or related associations (two persons). The interviews were held using a predefined questionnaire. The results of the two elicitation sessions (workshop and series of interviews) were integrated for each of the four aspects mentioned earlier.

3. Results and discussion

Selection of main indicators

Of the 43 experts, 29 responded to the first Delphi round, 26 to the second round, and 23 to the third round. In total 21 experts from 12 different European countries responded to each of the three rounds.

As a result of the first round, three additional indicators were included: 'ability of *Fusarium* species to synthesise new mycotoxins' for wheat cultivation, and 'water activity profiles recorded during the wet phase processing' and 'fractions of the cereal grains used in the final feed and food product' (whole grain or outer layer of the grains compared to the inner starchy endosperm only) for wheat processing. These three additional indicators were included for evaluation in the second Delphi round. The 12 key indicators resulting from the three Delphi rounds, together with their ranks are presented in Table 1, per stage of the chain.

During the Delphi elicitation, the experts recommended that indicator interaction should be analysed. Potential indicators were identified for further research. The experts considered cultivation to be the most important stage of the wheat supply chain regarding occurrence of *Fusarium* spp. related EM. The results confirm that the selected key indicators for this stage did not differ much from factors influencing specific production of known *Fusarium* spp. mycotoxins during wheat cultivation (e.g. see EC, 2006a). However, additional indicators including plant health (stress factors), fungal species co-formation, regional infection pressure and food safety awareness were identified. These factors may have special significance for EM identification. In the subsequent chain stages, *Fusarium* spp. related mycotoxin occurrence is generally managed and emerging risk is mainly related to human errors and uncertainty in measurements regarding handling, distribution and use of contaminated fractions and batches.

Identification of information sources

Many (potential) information sources on the selected key indicators (presented in Table 1) were identified in the three specific European countries and at the European level. However, accessibility of data and lack of particular data affect the applicability of information sources in EM identification (the information sources and accessibility are presented, per indicator, in Van der Fels-Klerx and Booij, 2008). Data is dispersed between stakeholders, and organised data/information management throughout the chain is generally lacking. In order to fully utilise the information potential, data from farmers, trade organisations and processors on the key indicators should be made available and be as transparent as possible. The availability of information from these economic actors should improve enormously if systemised and structured. Also, traceability systems that operate with a smaller granularity, or batch size, will need to be used. Improved traceability systems which are extended with additional information are needed before an EM identification system can be utilised optimally.

In addition to the problem of data availability, data quality is variable. Advanced information systems with precise and high data quality are available for several indicators (e.g. climate data), whereas for others only best guesses can be made due to lack of information (e.g. awareness of food safety). The quality of the available input information should be evaluated in the EM identification system.

Applicability of information model

The applicability of the theoretical information model to the development of an EM identification system, presented in Van der Fels-Klerx *et al.* (2008) depends on:

1. Knowing the relative impact (value of the regression coefficient) of each indicator, preferably at each relevant level of detail with regard to time and location.

Table 1. The selected 12 key indicators (in order of importance) for identification of emerging mycotoxins, per stage of the wheat supply chain, as resulting from the Delphi study (n=23 experts).

Rank	Wheat supply chain stage		
	Cultivation	Transport and storage	Processing
1	relative humidity/rainfall	water activity in kernels	grain quality data
2	crop rotation (pre-crop)	relative humidity (product)	fractions of the cereal grains used
3	temperature	ventilation	water activity in kernels
4	tillage practice	temperature	traceability and quality systems
5	water activity in the kernels	storage capacity and logistics	carry over of contamination
6	crop variety	grain quality	awareness of food safety
7	harvest conditions	carry over of contamination	blending practices
8	changes in fungal populations	traceability and quality systems	new/improved detection methods
9	fungicide use	blending practices	national and EU legislation
10	plant health (stress factors)	awareness of food safety	number of products passing through national borders without inspection
11	regional infection pressure	level of technology used	level of technology used
12	awareness of food safety	national and EU legislation	ventilation

2. Knowing interactions among different indicators (additive, multiplicative, etc.) and their relative impacts.
3. The availability of information on the indicators at the appropriate scale in time and space.

Due to the difficulty in obtaining datasets or other information from which the impacts of all selected key indicators and their interactions can be estimated, the theoretical model can only serve as a basic concept that simplified systems can be developed and tested from. Basic estimations with the proposed model could be done on (validated) accurate forecasts for known mycotoxins. These forecasts should be as local as possible, e.g. using the models developed by Hooker *et al.* (2002) and Franz *et al.* (RIKILT, the Netherlands, unpublished data) to predict deoxynivalenol contents in wheat on a regional basis. Further steps could include the additional indicators either at a quantitative and/or a more qualitative basis. When regression coefficients cannot be estimated, some indicators can be considered as modifying factors (qualitatively) increasing or decreasing the assessed EM occurrence. The extent of change can be estimated from qualitative information and/or expert knowledge. Such an exercise is presented at the end of this section.

The future challenge lies in quantifying the impact of the key indicators, starting with highest ranked, hereby taking into account how the information for those indicators could become available and at which scale (time, location). To optimise the model, the organization of data in the supply chain and aggregation of information at a higher (regional) scale is needed. Registering and storing detailed data from each individual agricultural field, and associating this to each batch forwarded to the processor stage, may generate the data needed for analysis and model building. A registration system monitoring all key indicators would allow much more feasible and precise EM assessments. At a high spatial scale and with merged product batches, information has to be aggregated and combined with information at high (less detailed) spatial or organisational level. Because most current registration systems are location or geographically bound, information on the indicators is best retrieved when linked to origin (location) of batches, and stored and presented using a Geographical Information System (GIS). GIS is a computerised system capable of assembling, storing, manipulating and displaying data georeferenced using geographical coordinates (latitude and longitude). An application of GIS to a related field of interest can be found in Battilani *et al.* (2006). In future applications of such systems GIS-based databases could generate information maps for the different key indicators and fed to the EM identification model, resulting in GIS based EM assessments. See Figure 1 for an illustration of the envisioned geographical EM identification system (GEMIS).

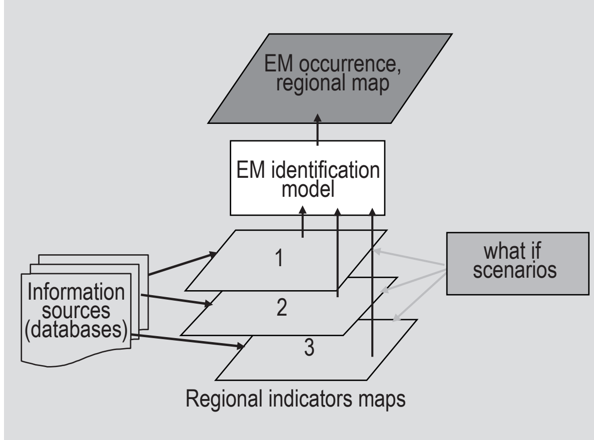

Figure 1. Outline of the envisioned geographical emerging mycotoxin (EM) identification system.

Because most risk management activities start with queries relating to hazard origin and entry into the supply chain, overlays of GIS maps with indicator values, in combination with model results are a promising application. Hence, origin of batches and of specific risk profiles are considered leading issues for future modelling approaches. In a GIS environment, region specific models and/or model input values can be used, depending on local model performance and information availability. Varying the input values for one or more indicators of the EM identification system will enable a risk manager to use scenario-based risk analysis using a structured 'what if' approach.

A simple version of the envisioned GIS-based EM identification system has been built for demonstration purposes. This demo, GEMIS, focuses on assessing EM occurrence during wheat cultivation. The underlying model is based on a predictive model for deoxynivalenol that includes several quantitative weather-related factors (Hooker *et al.*, 2002), extended with a qualitative indicator 'cereality', defined as the area of cereal crops grown as a percentage of the total available arable land in a given region. Cereality represents the regional infection pressure due to cereal agriculture (S.G. Edwards, Harper Adams University College, UK, personal communication). For illustration of GEMIS applicability for scenario analyses, Figures 2A-C provide example output of the current demo version in a baseline (Figure 2A) and two alternative scenarios: climate change (Figure 2B) and cereality (Figure 2C).

Stakeholder needs

The following sections present a summary of the integrated results of the two sessions which were aimed at exploring the stakeholders' needs with regard to EM management.

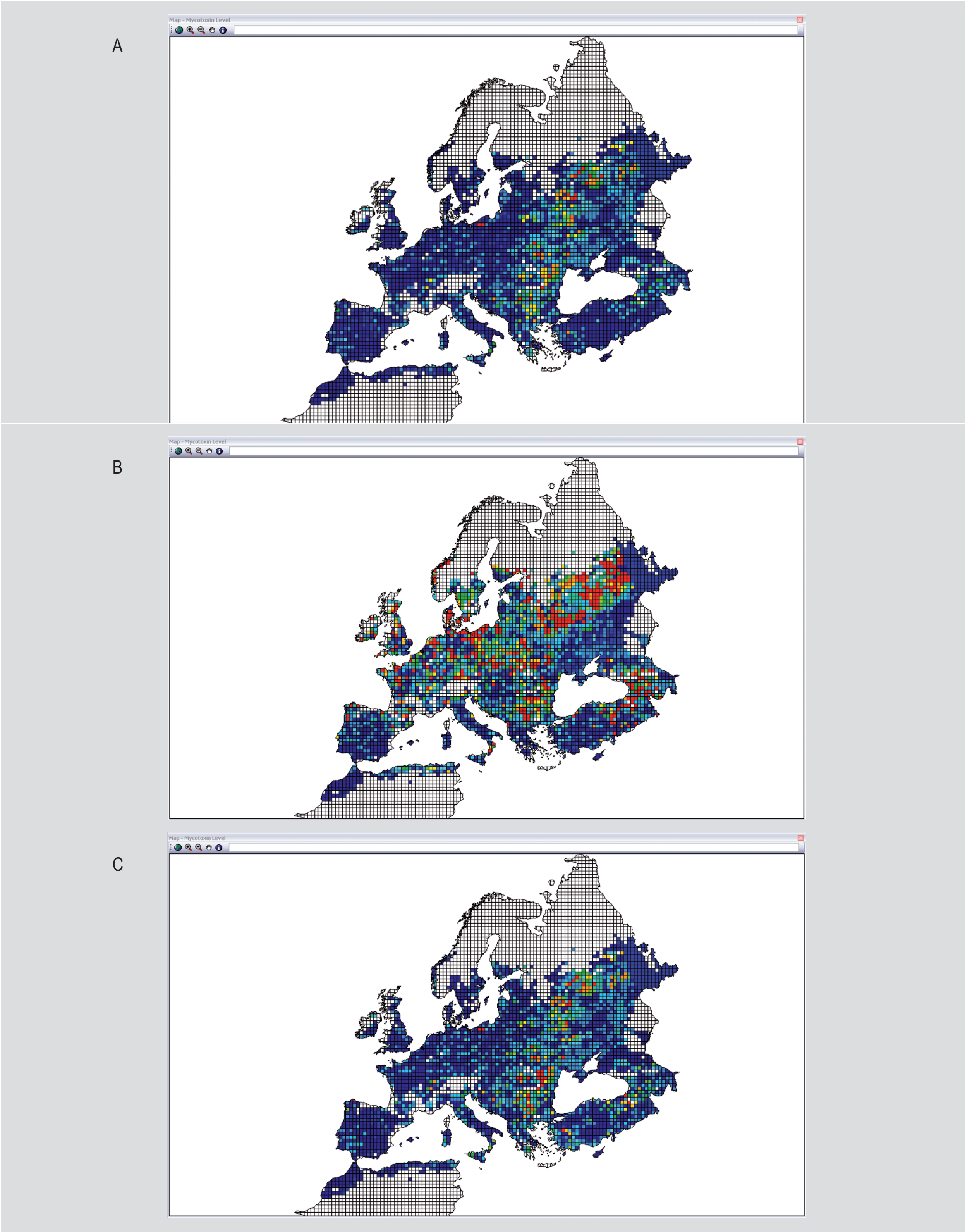

Figure 2. (A) Example of regionally assessed emerging mycotoxins in Europe, resulting from the demo version of the geographical emerging mycotoxin identification system (GEMIS). (B) Example of scenario analysis regarding climate change. Compared to the example presented in (A), daily temperature around heading is increased with 2 °C and daily rainfall with 3 mm. (C) Example of scenario analysis regarding the amount of cereals grown in a certain area in relation to the total arable land (cereality). Compared to the example presented in (A), cereality is increased with 20%. Grid size of shown GEMIS maps is 50 km^2. Indications (different colours) provided are for illustration purposes only.

Current practices

Current EM management of wheat supply chains varies from intensive use of information on most of the key indicators to visual inspection and laboratory analysis of harvest of questionable quality upon delivery to mill or import. For both authorities and industry, analysis of mycotoxin contamination is the main source of information. In feed and food industries, the mycotoxin testing regime is designed according to a quality assurance regime, in order to meet the specified demands from customers and (inter)national authorities. In the food industry, analysis is performed to ensure legal compliance with Regulation (EC) No. 1881/2006 (EC, 2006b), whereas the feed industry ensures compliance with guidance values for several *Fusarium* spp. toxins, as published in Commission Recommendation (EC) No. 576/2006 (EC, 2006c). Factors influencing sampling frequency include company size and the extent to which companies and regions have been affected by mycotoxin infestation historically. Informal communication and news from visual inspections are frequently used by authorities and traders to increase or decrease sampling frequency. Uncertainty arises when production circumstances are variable or unusual. Sampling errors and uncertainty in test results are also a matter of concern. In such situations model estimations may support future decision making. Electronic systems for EM identification are not fully developed. However, Finland has a national mycotoxin management scheme in the form of a central database to which all stakeholders contribute using many of the key indicators that were selected in this study for wheat cultivation. The results are available to all stakeholders, with different levels of aggregation depending on the specific customer, for use in risk management practices.

Add-on functionality

All stakeholders expressed a general interest in an EM identification system in wheat supply chains, and considered it a useful tool for estimation of mycotoxin contamination, thereby improving risk management by control and monitoring and, ultimately, reducing animal and human health risks. It was suggested that the system be expanded to cover not only EM but also known mycotoxins in wheat supply chains. Industry chain members considered an expanded system useful for decision making upon processing units, purchasing new lots, and laboratory analysis. In their opinion, the system would be a welcome tool for both short and long-term decision making, by providing information pertinent to purchasing, sourcing and geography. An EM identification system would provide opportunities for authorities to plan and execute risk-based and tailored activities, such as monitoring, inspection and sampling, thereby increasing efficiency and reducing resource use by authorities and supply chain members alike.

Potential information

The stakeholders considered cultivation to be the most important stage for proactive (emerging) mycotoxin management. Consequently, the most important indicators refer to this stage and rely on information from the farmers. For the subsequent wheat supply chain members, it is essential that information is organised separately for each stage, allowing dynamic adaptation of risk management according to information regarding preceding stages, e.g. increasing sample frequency or varying processing practices (Scudamore *et al.*, 2007).

Information needs and requirements

Both stakeholder groups emphasised the importance and simplicity in accessibility and reading format regarding the output from the envisioned EM identification system. An online searchable database was considered an appropriate tool for transmission and sharing of information, optimally displayed in the form of field maps, for use in purchasing and targeted sampling. The system should provide anonymous and aggregated data to all stakeholders and regarding Europe as a whole (at national or regional level). Other emphasised issues were trustworthiness of information sources and reliability of system results, stressing that output would be estimates with accuracy depending on level of accessibility and detail of information rather than evidence of EM occurrence. This was considered essential to reduce the risk of severe adverse market and trade repercussions.

From the stakeholder study, it was concluded that for the EM identification system to be applicable on a large scale (up to the European level), input from all stakeholders of the wheat food and feed supply chain is required. However, willingness and ability to share such information may not be equal along the chain, requiring close collaboration between authorities, research, farmers and industry for success. Improved interaction and information exchange (quality, frequency, speed) between the public authorities and the feed and food industries is essential to avoid information gaps and loss along the chain.

4. Conclusions

The research described in this paper addressed various basic elements in developing an EM identification system in wheat feed and food supply chains. The obtained results provide a systematic basis for setting up such a system. Although this study was focused on a specific hazard, the knowledge and insights have relevance for development of any management and information sharing system for (emerging) feed and food safety hazards. The most important key indicators for identifying EM originate at wheat cultivation. These include: relative humidity/rainfall, crop rotation, temperature, tillage practice, water activity in the kernels, crop variety, harvest conditions, changes in fungal populations, fungicide use, plant health, regional infection pressure and food safety awareness. Information sources on most of these key indicators are available at the European country level. However, most of the information is in the hands of the farmers and other economic actors, and is not currently accessible temporally or in right format. Therefore, the underlying model for an EM identification system must be flexible regarding information availability. Starting with region-based predictive models for known mycotoxins, further elaboration should include additional (often more qualitative) indicators and expansion of geographical and indicator relevant information as this becomes available in a reliable manner. The various groups of stakeholders could foresee large benefits of the envisioned EM identification system, including improved risk management, improved control and monitoring strategies and, ultimately, reduced risk to animal and consumer health. However, success relies heavily on the willingness and ability of actors to share information. This could be supported by improved interaction, anonymous data and trust between stakeholders.

Acknowledgements

The research described in this paper is performed within the context of the European project MYCONET. The authors gratefully thank all national funders associated with this project, Advisory Board Members, and Nordic Innovation Centre. The contribution of all experts and stakeholders who participated in the Delphi study, the interviews and the workshop is greatly acknowledged, as well as the contribution of O. Reykdal (MATIS, Iceland), C. Waalwijk and P. Kastelein (Plant Research International, the Netherlands), J.M. Costa and F.M. Bernardo (Direcção Geral de Veterinária, Portugal).

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