MYMATCH

Deliverable 4.1

State-of-the-art report on existing knowledge and tools to assess MY impact on food safety under CC conditions

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Nature of the deliverable		
R	Document, report	X
DMP	Data Management Plan	
DATA	Data sets, microdata, etc	
ETHICS		
DEC	Websites, patent filings, videos, etc	
OTHER		

Dissemination level		
PU	Public (*fully open*)	
SEN	Sensitive (*limited under the conditions of the Grant Agreement*)	X
EU CI	EU Classified (*eu-restricted, eu-confidential, eu-secret under Decision 2015/444*)	

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Project's summary

Climate change amplifies food safety risks by fostering the proliferation of pathogens and contaminants in the food supply chain and introducing unfamiliar or novel hazards.

Among the food safety threats, because of their ubiquity, MYMATCH will consider the effects of climate change on a selection of mycotoxins (related to fungi belonging to Aspergillus, Fusarium, and Alternaria) occurring in maize, wheat, tomato, and nuts.

Thanks to a strong and multi-actor partnership, MYMATCH will contribute to:

1. the prediction and mitigation of risk related to fungi and mycotoxin occurrence,
2. the assessment of mycotoxins exposure in humans (concerning different diets) and animals, and
3. the implementation of proper risk management measures.

This will be achieved with data collection taking place at different levels, from literature considering events that happened in the past, under controlled environments and open fields, enabling the generation of the missing datasets needed to fulfil the project aims.

This will support the development and implementation of fungi and mycotoxin predictive models founded on accurate climate change scenarios to anticipate the changes in mycotoxin occurrence in European food systems.

MYMATCH AI mycotoxin management Platform will be the final output, the support for all food system actors with tailored predictions, recommendations, and mitigation approaches. By using this platform, the agri-food researchers, farmers, industry stakeholders, and policymakers, involved in the project through the MYMACTH's Multi-Actor Framework, will be assisted in taking threat-mitigation initiatives and in decision-making, both in the short- and strategic long-term planning.

MYMATCH tools and methods will be generated in a way that is easily extendable to other contaminant issues and co-created and developed with a strong interaction with potential users like EFSA.

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Document's objective and executive summary

Document Objectives

The objective of Deliverable 4.1 is to establish a comprehensive state-of-the-art overview of current knowledge, datasets, and analytical tools related to mycotoxin occurrence, ecology, and detection under changing climatic conditions.

Specifically, this document aims to:

- Collect and systematise existing information from scientific and grey literature on the ecology and occurrence of mycotoxin-producing fungi (*Aspergillus*, *Fusarium*, *Alternaria*) in key crops (maize, wheat, tomato, and nuts);
- Evaluate the availability, quality, and interoperability of existing European datasets on mycotoxin occurrence, with emphasis on FAIR data principles;
- Review rapid and on-site analytical methods suitable for early detection of mycotoxins and for integration into future climate-informed surveillance systems;
- Identify knowledge gaps, methodological inconsistencies, and critical needs to support the development of predictive models and risk-assessment tools in subsequent MYMATCH work packages.

The deliverable therefore serves as the scientific foundation for the MYMATCH data-generation, modelling, and risk-assessment activities to be developed under WP5–WP8, ensuring that all outputs are based on harmonised, high-quality, and reusable information.

Executive Summary

Deliverable D4.1 provides a detailed assessment of the current scientific and data landscape on mycotoxin risks in the context of climate change.

Through an extensive literature and database review, it consolidates information on (i) fungal ecology, (ii) mycotoxin occurrence in European food systems, and (iii) analytical tools available for monitoring and management.

The review reveals a broad but fragmented knowledge base. Thousands of studies address mycotoxin contamination in maize, wheat, tomato, and nuts, yet the data are often inconsistent, aggregated, and lacking metadata necessary for integration or climate modelling.

A dedicated mapping of European data repositories—covering EFSA, national monitoring systems, and open-science platforms—highlights strong analytical capacity but weak data stewardship, with limited interoperability and discoverability of datasets.

In parallel, the document reviews emerging rapid detection technologies, such as biosensors, immunoassays, spectroscopy, and portable mass spectrometry. These tools increasingly complement conventional LC-MS/MS methods, offering opportunities for real-time, field-level screening and early-warning systems.

However, their adoption remains uneven, particularly for Alternaria toxins in tomato products, where few validated rapid assays exist.

Overall, the results underline that while Europe's analytical infrastructure for mycotoxin control is well developed, its information architecture remains fragmented. Harmonised metadata standards, FAIR-compliant data sharing, and integration across regulatory, research, and national systems are essential to enable predictive, climate-resilient risk assessment.

The insights and recommendations provided in D4.1 will guide the creation of robust, interoperable datasets and inform the design of MYMATCH's predictive modelling and decision-support tools for food safety under evolving climate scenarios.

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List of abbreviations

AF — Aflatoxin

AFB1 — Aflatoxin B1

AFSCA — Federal Agency for the Safety of the Food Chain (Belgium)

AGRITOX — European Agricultural Toxicology Database

AOH — Alternariol

AME — Alternariol Monomethyl Ether

ALT — Altenuene

ANSES — Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (France)

aw — Water Activity

BAES — Bundesamt für Ernährungssicherheit (Austria)

BFSA — Bulgarian Food Safety Agency

BfR — Bundesinstitut für Risikobewertung (Germany)

CC — Climate Change

DCF — Data Collection Framework (EFSA)

DON — Deoxynivalenol

EEA — European Environment Agency

EFSA — European Food Safety Authority

ELISA — Enzyme-Linked Immunosorbent Assay

ELS — Extensive Literature Search

ENN — Enniatin

EURL — European Union Reference Laboratory

EU — European Union

FAIR — Findable, Accessible, Interoperable, and Reusable (data principles)

FB1 — Fumonisin B1

FPIA — Fluorescence Polarisation Immunoassay

FT-NIR — Fourier Transform Near-Infrared Spectroscopy

HPLC — High-Performance Liquid Chromatography

HRMS — High-Resolution Mass Spectrometry

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JRC — Joint Research Centre (European Commission)

LC-MS/MS — Liquid Chromatography Tandem Mass Spectrometry

LOD — Limit of Detection

LOQ — Limit of Quantification

MIR — Mid-Infrared Spectroscopy

MS — Mass Spectrometry

MY — Mycotoxin

NRL — National Reference Laboratory

OTA — Ochratoxin A

PDA — Potato Dextrose Agar

PRISMA — Preferred Reporting Items for Systematic Reviews and Meta-Analyses

QA/QC — Quality Assurance / Quality Control

RASFF — Rapid Alert System for Food and Feed

SERS — Surface-Enhanced Raman Spectroscopy

SSD2 — Standard Sample Description version 2 (EFSA format)

TeA — Tenuazonic Acid

TEN — Tentoxin

TRFIA — Time-Resolved Fluorescence Immunoassay

UHPLC — Ultra-High-Performance Liquid Chromatography

UNIPR — University of Parma

WHO — World Health Organization

ZEN / ZEA — Zearalenone

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1. Introduction and objectives

Mycotoxins—secondary metabolites produced mainly by some fungal species belonging to *Aspergillus, Fusarium*, and *Penicillium*—remain among the most significant natural contaminants threatening food safety worldwide. Both fungal growth and toxin biosynthesis is tightly regulated by environmental factors such as temperature, humidity, CO_2 concentration, and crop stress. As the climate warms and weather patterns become increasingly unpredictable, the ecological niches of mycotoxigenic fungi are shifting across Europe, changing both the geographical distribution and intensity of contamination.

Studies have already documented a northward migration of aflatoxin-producing species (*Aspergillus flavus*), increased *Fusarium* toxin prevalence in temperate zones, and greater inter-annual variability in *Alternaria* and *Penicillium*-related toxins under fluctuating moisture regimes (Battilani et al., 2016; Medina et al., 2017; Casu et al., 2024; JRC, 2023). These transformations threaten to blur traditional risk boundaries and require risk-assessment frameworks that are dynamic, data-rich, and climate-aware.

Against this backdrop, Work Package 4 (WP4) of MYMATCH - "Setting the Ground: Existing Knowledge and Tools to Assess Mycotoxin Impact on Food Safety under Climate-Change Conditions" - was conceived to provide the scientific foundations for all subsequent project activities. WP4 integrates three complementary lines of work:

Collection and systematisation of existing knowledge - Through an extensive review of the scientific and grey literature, WP4.1 consolidated current evidence on mycotoxin occurrence and co-occurrence. This deliverable followed PRISMA guidelines to ensure methodological transparency. Particular attention was paid to the quality and structure of available datasets—whether from EFSA, national monitoring programmes, or research projects such as MyToolBox, MycoKey, and HOLiFOOD. The synthesis revealed a broad but fragmented evidence base: data are abundant but often aggregated, lacking the metadata needed for reuse. Many studies report only mean concentrations or exceedance rates, with minimal traceability on sampling, location, or analytical quality controls. Moreover, literature-derived data frequently suffer from publication bias, as non-compliant or high-contamination results are disproportionately published while compliant findings remain underrepresented

(Eskola et al., 2020; Khodaei et al., 2021). These gaps hinder quantitative synthesis and compromise representativeness.

Mapping of data quality, curation, and stewardship practices - A detailed inventory of existing European data sources—covering EFSA databases, national control programmes, and open repositories such as Zenodo and data.europa.eu—was performed to assess their interoperability and FAIR compliance. The evaluation demonstrated that, although analytical quality is assured across the EU through the EURL/NRL network, data stewardship remains the weakest link. Inconsistent metadata, limited accessibility, and the lack of persistent identifiers prevent full integration of data across Member States. Establishing harmonised criteria for data acceptance, documentation, and curation emerged as a prerequisite for any reliable climate-informed risk assessment (EFSA 2024; EEA 2025).

Review of rapid and on-site detection methods - Complementing the data analysis, WP4.3 conducted a systematic review of rapid detection technologies applicable throughout the food supply chain. This included lateral-flow immunoassays, electrochemical biosensors, portable spectroscopic devices (NIR, MIR, Raman), and hyperspectral imaging systems (De Girolamo et al., 2019; Femenias et al., 2022; Freitag et al., 2022). These methods are increasingly suitable for in-field or processing-line applications and can complement laboratory analysis by enabling real-time screening and decision-making. The review also highlighted the critical importance of stakeholder involvement—from farmers to industry laboratories—in defining user needs, as end-user profiles strongly influence adoption and usability (Adunphatcharaphon et al., 2022; Tittlemier et al., 2022).

By integrating these three strands—literature synthesis, data stewardship analysis, and technological landscape review—WP4 provides a comprehensive picture of Europe's current readiness to monitor and manage mycotoxin risks under changing climate conditions. The results reveal a dual challenge: while analytical capability and emerging diagnostic tools are advancing rapidly, the underlying information architecture remains fragmented, inconsistent, and often inaccessible.

The work presented in this chapter therefore establishes both the state of the art and the foundation for progress. It defines what constitutes fit-for-purpose data for mycotoxin risk assessment, outlines best practices for data collection, curation, and

sharing, and identifies promising technological innovations for field-level detection. Together, these findings will inform the generation of new, high-quality data within MYMATCH and underpin the project's forthcoming guidelines, policy briefs, and training materials aimed at supporting Europe's transition toward a transparent, interoperable, and climate-resilient food-safety data ecosystem.

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2. Data collection from the scientific literature

2.1 Methodology

The ELS was performed according to PRISMA criteria and using the search strings reported below.

The literature search was performed screening PUBMED, SCOPUS and WOS.

The retrieved hits were downloaded, inspected according to the criteria reported below and classified using Rayyan. The final selection was exported as Zotero database and used for further data extraction.

Keywords used for cropping:

MAIZE

[(maize OR corn OR Zea mays)**] AND [**(fung* OR Fusarium OR Aspergillus OR Penicillium OR Claviceps OR Alternaria) **OR** (Mycotoxin* OR toxin* OR Aflatoxin* OR AF* OR Fumonisin OR FB* OR Deoxynivalenol OR DON OR Ochratoxin OR OTA OR Zearalenone OR ZEN OR ZEA OR Patulin OR PAT OR T2 OR HT2 OR Trichothecene* OR ergot alkaloids OR Beauvericin OR BEA OR Enniatin* OR ENN OR moniliformin OR MON OR AAL TB toxin OR Alternariol) OR mycotoxin*(near)occur ORmycotoxin (near)Cooccur*OR mycotoxin (near)Co-occur* OR mycotoxin (near)Modified OR mycotoxin (near)Masked OR mycotoxin (near)Combined OR mycotoxin (near)Mixture OR mycotoxin (near)Conjugated**)] AND [(**Cropping system OR Harvest OR Pre-harvest OR Irrigation OR Pest control OR Disease control OR Biocontrol OR Occurrence OR co-occur* OR growth OR sporulation OR ecolog* OR water activity OR Climat* change* OR meteorological(s)change* OR global warming OR weather conditions OR tropical* OR temperature OR climat* variation* OR metereological* variation*) **OR** (Post-harvest OR processing OR products OR storageORDerived products OR Processed products OR Final products)**]**

WHEAT

[(wheat OR Triticum)**] AND [**(fung* OR Fusarium OR Aspergillus OR Penicillium OR Claviceps OR Alternaria) **OR** (Mycotoxin* OR toxin* OR Aflatoxin* OR AF* OR Fumonisin OR FB* OR Deoxynivalenol OR DON OR Ochratoxin OR OTA OR Zearalenone OR ZEN OR ZEA OR Patulin OR PAT OR T2 OR HT2 OR Trichothecene* OR ergot alkaloids OR Beauvericin OR BEA OR Enniatin* OR ENN OR moniliformina OR MON OR AAL TB toxin OR Alternariol) OR mycotoxin*(near)occur ORmycotoxin (near)Cooccur*OR mycotoxin (near)Co-occur* OR mycotoxin (near)Modified OR mycotoxin (near)Masked OR mycotoxin (near)Combined OR mycotoxin (near)Mixture OR mycotoxin (near)Conjugated**)] AND [(**Cropping system OR Harvest OR Pre-harvest OR Irrigation OR Pest control OR Disease control OR Biocontrol OR Occurrence OR co-occur* OR growth OR sporulation OR ecolog* OR water activity OR Climat* change* OR meteorological(s)change* OR global warming OR weather conditions OR tropical* OR temperature OR climat* variation* OR metereological* variation*) **OR** (Post-harvest OR processing OR products OR storageORDerived products OR Processed products OR Final products)**]**

TOMATO

[(tomato OR Solanum lycopersicum)**] AND [**(fung* OR Fusarium OR Aspergillus OR Penicillium OR Claviceps OR Alternaria) **OR** (Mycotoxin* OR toxin* OR Aflatoxin* OR AF* OR Fumonisin OR FB* OR Deoxynivalenol

OR DON OR Ochratoxin OR OTA OR Zearalenone OR ZEN OR ZEA OR Patulin OR PAT OR T2 OR HT2 OR Trichothecene* OR ergot alkaloids OR Beauvericin OR BEA OR Enniatin* OR ENN OR moniliformina OR MON OR AAL TB toxin OR Alternariol) OR mycotoxin*(near)occur ORmycotoxin (near)Cooccur*OR mycotoxin (near)Co-occur* OR mycotoxin (near)Modified OR mycotoxin (near)Masked OR mycotoxin (near)Combined OR mycotoxin (near)Mixture OR mycotoxin (near)Conjugated**)] AND [(**Cropping system OR Harvest OR Pre-harvest OR Irrigation OR Pest control OR Disease control OR Biocontrol OR Occurrence OR co-occur* OR growth OR sporulation OR ecolog* OR water activity OR Climat* change* OR meteorological(s)change* OR global warming OR weather conditions OR tropical* OR temperature OR climat* variation* OR metereological* variation*) **OR** (Post-harvest OR processing OR products OR storageORDerived products OR Processed products OR Final products)**]**

Keywords used for occurrence:

The one used for cropping plus the following string:

AND[(food OR breakfast cereal* OR gluten free product* OR bread OR pasta OR beer OR malt OR tomato OR paste OR sauce OR feed OR silage OR forage OR fodder OR hay OR concentrate OR snaplage OR earlage OR By-Products OR Co-Products OR meal OR grain OR whole grains OR compliant OR legislation)**]**

Exclusion and inclusion criteria

The resulting records should undergo a two-step selection procedure after duplicate removal:

1) **Screening of title and abstract** to identify potentially relevant studies that will be included for full-text screening, applying the eligibility criteria described in section 2.1. If the information contained in the title or abstract was not relevant to the research objectives, the article was not selected for full-text assessment.

2) **Publication date**: from 2014 to 2024

3) For occurrence data only those obtained in Europe

4) **Full-text screening.** Subsequent screening for studies passing the first step was based on the full-text article to assess if the article was relevant to the research objectives. Regarding occurrence, the presence of quantitative data was considered as inclusion criteria.

In addition, the following quality criteria were adopted for exclusion:

- Lack of information about geographical origin (at least at the level of country of origin)
- Lack of information about harvest/collection year

- Data reported for highly formulated products
- Lack of information about analytical quality (i.e. no LOD, no LOQ)
- Data obtained with a method different from the following: ELISA, LC-MS, LC-DAD, LC-UV, LC-FLD

Additional exclusion criteria were set for mycotoxin occurrence as following to ensure the collection of relevant data for the project :

- lack of geographical origin or collection year,
- lack of information about analytical quality or inadequate methodology
- highly formulated products
- non-European products

2.2 Results

The ELS was performed in March-April 2025 by 2 different persons independently. The total number of papers is reported in Table 1.

Total number of papers	Maize	Wheat	Tomato
Scopus	3110	2621	1948
WoS	2850	2340	441
Medline	1321	847	151

Table 1 : ELS results before cleaning and filtering

The papers were uploaded to Rayyan and the duplicates were removed. Afterwards, the title and abstract were screened independently by two persons for adherence to the quality criteria.

Selected literature was classified according to the following classes:

- Fungal ecology
- Mycotoxin occurrence
- Management (field, processing, storage, decontamination)

After cleaning and classification, the ELS returned the following number of papers :

Total number of papers	Maize	Wheat	Tomato
Fungal ecology	47	58	13
Mycotoxin occurrence	139	215	28
Management	662	677	407

Table 2: ELS results after cleaning and filtering

The list of reference was fully downloaded and uploaded to Zotero. Full-text screening for inclusion and data collection was performed by partners according to their expertise.

Data were collected in a common excel template and uploaded to the MyMatch repository.

2.2.1 Results for ecology data in maize

Substrates

The trials performed in the reviewed studies have mostly been conducted under controlled conditions, primarily *in vitro*, except for one study in which the test was carried out *in planta*. Maize was the most frequently employed substrate, appearing in 15 studies (9 as grains, 4 as maize-based medium, 1 as plant, and 1 as maize stalk), followed by wheat, which was used in 4 (2 as grains, 1 as wheat-based medium, and 1 as plant). All other substrates, comprising thirteen different food- or feed-based matrices and eight chemically defined media, were reported only once or twice across the dataset.

Fungal species

The fungal species investigated belonged exclusively to two genera: *Aspergillus* (16 papers) and *Fusarium* (17 papers). Among *Aspergillus* species, *A. flavus* was the most frequently studied, while among *Fusarium* species, *F. graminearum* and *F. verticillioides* were the most investigated. Focusing on maize-based substrates, *A. flavus* and *F. graminearum* were each investigated in 5 studies, while *F. verticillioides* was reported in 4.

Ecophysiological parameters

The main ecophysiological parameters investigated concerned fungal growth and mycotoxin production. Growth rate was the most frequently assessed parameter, reported in 14 of the reviewed studies. Regarding mycotoxin production, aflatoxins, trichothecenes, and fumonisins were the most analysed compounds. Specifically, AFB1, DON, and FB1 were analysed respectively, in 11, 8 and 7 papers.

2.2.2 Results for ecology data in wheat

Substrates

Most of the trials were performed under controlled *in vitro* conditions, with only a limited number of assays conducted directly *in planta*. Wheat-based matrices were clearly dominant across the dataset, confirming the crop's central role as a model system for studying fungal growth and mycotoxin biosynthesis. Trials were mainly conducted in wheat-based medium, followed by wheat kernels and only seldomly by wheat plant tissues (spikes, stems).
Several comparative experiments were conducted using maize grains, barley-based medium or rice-based medium. PDA was also largely used as reference medium for baseline growth rate determination.

Fungal species

The fungal species investigated in the wheat dataset belonged predominantly to the *Fusarium* genus, with occasional studies on *Aspergillus* species under post-harvest or competition conditions. The most frequently examined taxa were *Fusarium graminearum*, *F. cerealis*, *F. meridionale*, *F. equiseti*, *F. asiaticum*, *F. proliferatum*.

Other species, such as *F. langsethiae* and *F. boothii*, appeared less frequently but remain relevant for northern and temperate European contexts. Overall, *F. graminearum* emerged as the key model organism, reflecting its primary role in Fusarium Head Blight (FHB) of wheat and its importance as a major producer of type B trichothecenes, especially DON and its acetylated derivatives.

Ecophysiological parameters

The main ecophysiological variables recorded in the wheat dataset were fungal growth rate, colony expansion, and toxin production, as functions of environmental conditions such as temperature, water activity (a_w), and pH.

Growth kinetics were typically determined on wheat grains or synthetic media adjusted to a_w between 0.85 and 0.995, and temperatures ranging from 10 to 35 °C. Optimal growth was generally observed at 25 °C and $a_w \geq 0.98$ for *F. graminearum*, while *F. culmorum* showed slightly lower temperature optima (20–24 °C).

F. sporotrichioides and *F. langsethiae* displayed higher tolerance to low a_w, confirming species-specific ecological adaptation to cooler or drier climates.

Mycotoxin production was investigated in most studies, focusing mainly on DON, 3-AcDON, 15-AcDON, and other type B trichothecenes. ZEN, NIV, and T-2/HT-2 toxins were frequently co-analysed, providing insights into multi-toxin dynamics under varying conditions. Additional physiological endpoints included lag phase, spore germination, and inter-species interactions, particularly under combined stress factors (temperature × aw × CO_2).

2.2.3 Results for ecology data in tomato

Substrates

Most of the experiments were carried out under controlled in vitro conditions, mainly employing synthetic or semi-synthetic substrates. Potato Dextrose Agar (PDA) was by far the most frequently used medium, followed by Tomato Pulp Agar, Yeast Extract Agar, and other nutrient-rich media such as Carrot Sucrose Agar and Barley Sucrose Agar.

A few trials were performed using Tomato Juice or Tomato Leaves and Water Agar, reflecting an interest in natural, sugar-rich or acidic plant-based matrices suitable for mimicking infection substrates.

Overall, the dataset indicates a clear predominance of artificial media, with only limited use of natural plant materials (seeds or tissues).

Fungal species

The fungal species represented in the dataset belonged primarily to the Alternaria and Botrytis genera, with *Alternaria arborescens*, *A. alternata*, *A. solani*, *A. tenuissima*, and *Botrytis cinerea* as the most frequently studied taxa.

Other species appeared less frequently, including *Aspergillus flavus*, *Fusarium udum*, *Geotrichum candidum*, and *Phytophthora drechsleri f. sp. Cajani*.

The strong representation of *Alternaria* species highlights their importance as key pathogens in both vegetable and cereal crops, while *B. cinerea* remains a model organism for studies on fruit rot, oxidative stress, and post-harvest spoilage dynamics.

Ecophysiological parameters

The main ecophysiological variables assessed were temperature, water activity (aw), and pH, examined in relation to fungal growth kinetics and secondary metabolite production.

Temperature conditions ranged between 10 and 35 °C, with optimal growth typically observed around 25 °C, consistent with the mesophilic behavior of *Alternaria* spp. and *Botrytis cinerea*.

Recorded water activity (aw) values varied from 0.90 to 0.995, averaging 0.95, indicating the strong moisture dependence of these fungi for mycelial development and sporulation.

The pH of the media ranged from 4.0 to 8.0 (mean 6.0 ± 1.3), aligning with the optimal range for mesophilic and moderately acidophilic filamentous fungi.

Overall, the dataset reveals a focus on conditions favoring vegetative growth rather than reproductive or stress responses, with a strong emphasis on reproducible, standardized media to investigate fungal adaptation under moderate *aw* and pH variations.

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2.2.4 Results for occurrence data in maize

As a result of the bibliographic research conducted on March 19th 2025, 3101 records were retrieved from Scopus, 2850 records from Web of Science, and 1321 from Medline. Afterwards, Rayyan AI tool (Rayyan.ai) was employed to screen the papers in order to remove duplicate. Moreover, a screening of titles and abstracts was carried out manually to remove non-pertinent papers. After the last screening step, a total of 139 papers were subjected to full text screening according to the criteria listed above.

For each paper the following data were collected in an excel data sheet: country origin of samples, mycotoxin, region of sampling, sampling year, sampling point, sampling method, food item, analytical method, LOD or LOQ of the analytical method, unit of measurement, average occurrence, median occurrence, standard deviation, min-max occurrence, percentage of positive samples and co-occurrence. Only some of the data collected were available for each paper.

Selected papers and data extraction

The applied screening methodology allowed the identification of 24 studies that met the established inclusion criteria. Regarding the geographical origin of the studies, the country where each study was conducted corresponded to the origin of the analysed samples. As illustrated in Figure 1, several European regions show a very limited or even complete absence of studies reporting data of appropriate quality.

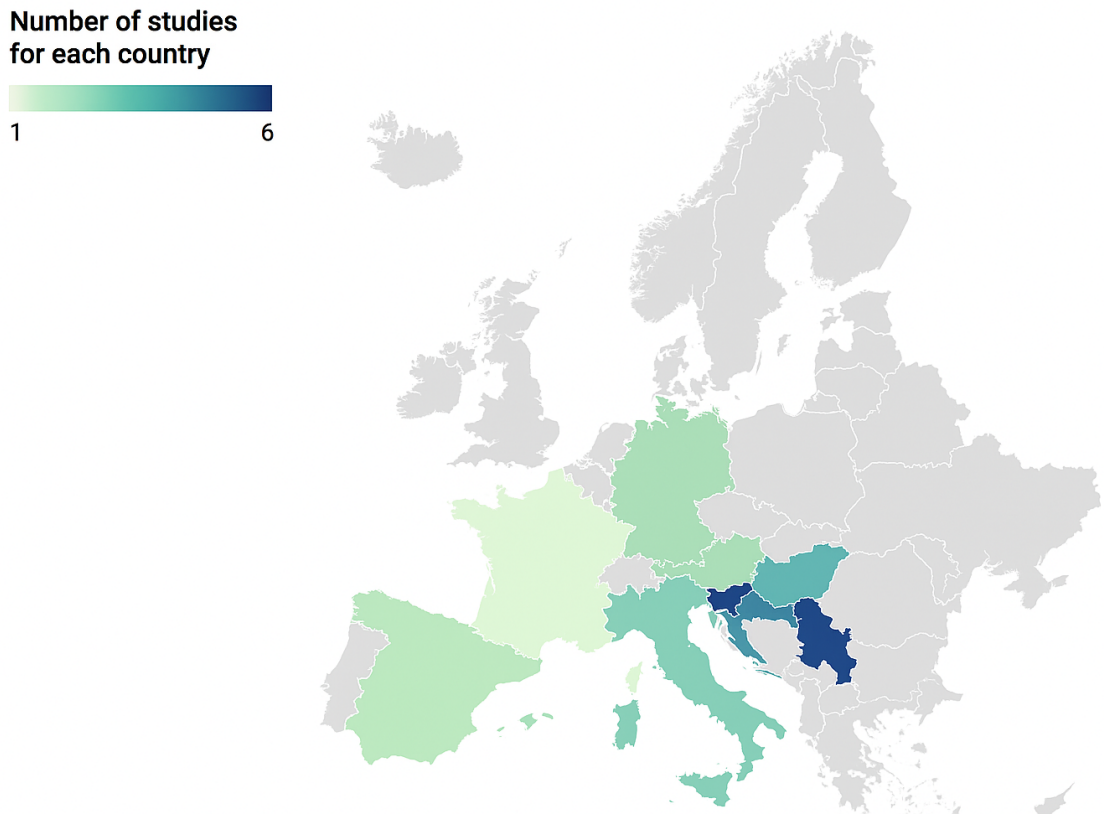

Figure 1. Geographic distribution of studies on mycotoxin occurrence in maize across Europe. The map uses varying shades to indicate the number of studies conducted in each country.

By examining the data collected, it can be noted that all studies analysed maize kernels, except for a single study focusing on maize flour. Regarding the sampling methods, 8 out of 24 studies followed the regulatory frameworks on sampling methodology (Commission Regulations No. 2006/401), while the other selected studies do not specify the sampling method used. Moreover, sampling occurred at preharvest, harvest, and postharvest stages. Concerning the analytical methods reported, they were varied and include LC-MS/MS, ELISA, HPLC-FLD, HPLC-DAD, and LC-HRMS with a higher prevalence of studies employed the former.

The selected papers, overall investigated the occurrence of both regulated and not regulated mycotoxins, considering both different country and harvesting year. With a single exception, all studies followed a multi-mycotoxin analytical approach.

The most frequently reported regulated mycotoxins were DON (9 studies), AFB1 (8 studies), ZEN (8 studies), FB1 (9 studies), OTA (5 studies), T-2 (6 studies), and HT-2 (4 studies).

A wide range of non-regulated mycotoxins were also identified in maize samples across various European regions, highlighting the complexity of contamination and the importance of monitoring beyond currently regulated compounds.

The co-occurrence was very frequent, although data were often presented as aggregated so the actual pattern of co-occurrence per sample was not easily derived.

2.2.5 Results for occurrence data in wheat

As a result of the bibliographic research conducted on March 19th 2025, 2621 records were retrieved from Scopus, 2340 records from Web of Science, and 847 from Medline. Afterwards, Rayyan AI tool (Rayyan.ai) was employed to screen the papers in order to remove duplicates. Moreover, a screening of titles and abstracts was carried out manually to remove non-pertinent papers. After the last screening step, a total of 215 papers were subjected to full text screening according to the criteria listed above.

For each paper the following data were collected in an excel data sheet: country origin of samples, mycotoxin, region of sampling, sampling year, sampling point, sampling method, food item, analytical method, LOD or LOQ of the analytical method, unit of measurement, average occurrence, median occurrence, standard deviation, min-max occurrence, percentage of positive samples and co-occurrence.

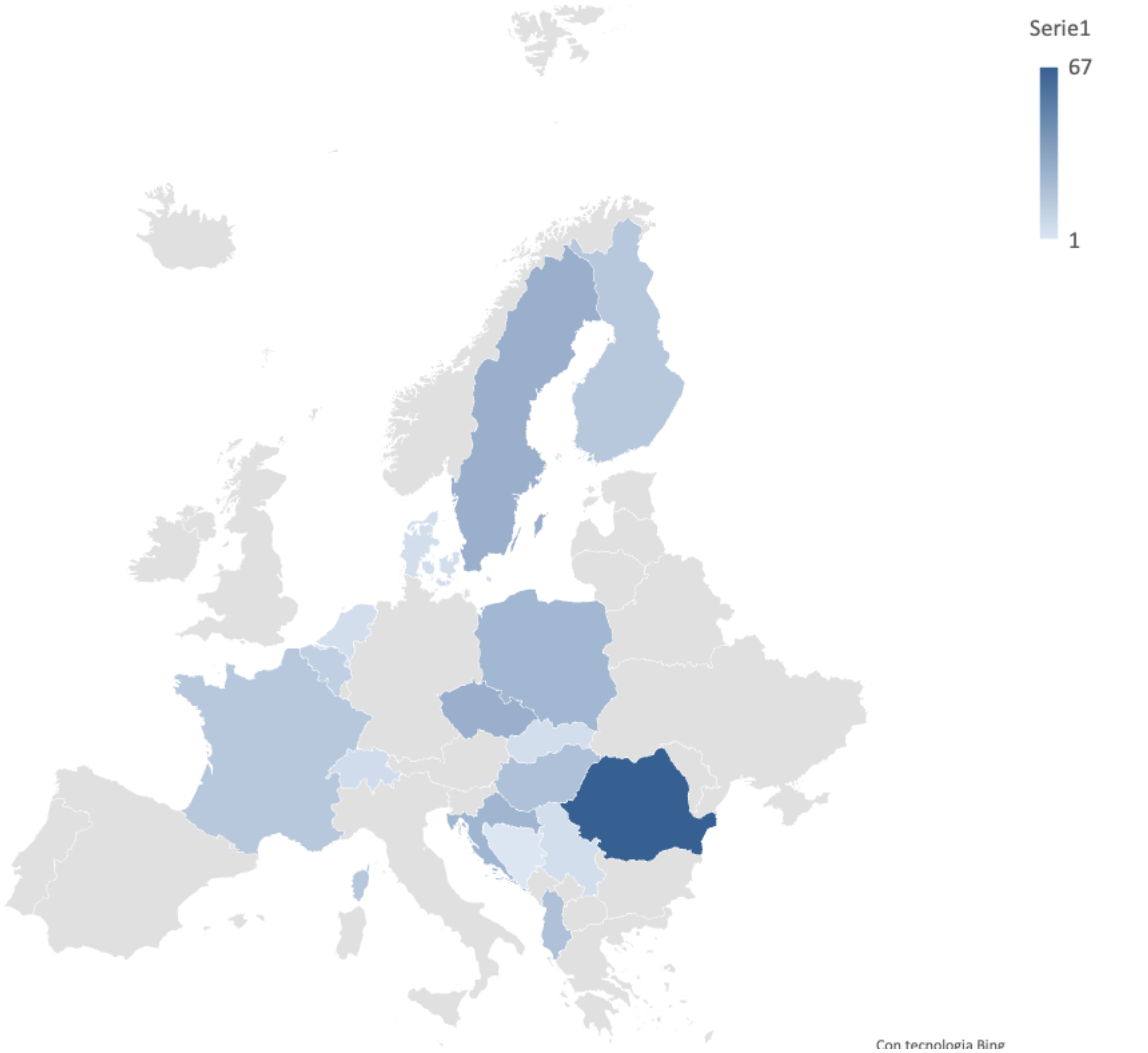

Figure 2. Geographic distribution of data collected on mycotoxin occurrence in wheat across Europe. The map uses varying shades to indicate the number of studies in each country.

Selected papers and data extraction

The applied screening methodology allowed the identification of 32 studies that met the established inclusion criteria. Regarding the geographical origin of the studies, the country where each study was conducted corresponded to the origin of the analysed samples. As illustrated in Figure 2, several European regions show a very limited or even complete absence of studies reporting data of appropriate quality. However, it should be noted that monitoring data are often not published in scientific papers if they do not pertain specific research projects. Therefore using data from the public scientific literature often results in a serious underestimation of the available occurrence data.

By examining the data collected, it can be noted that all studies analysed wheat kernels. Regarding the sampling method, selected studies do not specify the sampling method used. This is likely due to the fact that processed products are not easily traced back to the geographical origin of the raw material. Metadata information are often scant and strongly rely on what is reported on the label. Sampling occurred at preharvest, harvest, and postharvest stages without detailed information. Studies usually reported LC-MS/MS, as analytical method employed.

All studies followed a multi-mycotoxin analytical approach.

Most studies reported on the occurrence of DON and related modified forms, often co-occurring with other type A and type B trichothecenes (NIV, T-2 and HT-2) as well as ZEN. Aflatoxins were reported in only one study.

ENNs, BEA and MON were also reported in wheat as non-regulated mycotoxins, always co-occurring with major regulated ones.

The co-occurrence was very frequent, although data were often presented as aggregated so the actual pattern of co-occurrence per sample was not easily derived.

2.2.6 Results for occurrence data in tomato

As a result of the bibliographic research conducted on March 19th 2025, 1948 records were retrieved from Scopus, 441 records from Web of Science, and 151 from Medline. Afterwards, Rayyan AI tool (Rayyan.ai) was employed to screen the papers in order to remove duplicate. Moreover, a screening of titles and abstracts was carried out manually to remove non-pertinent papers. After the last screening step, a total of 28 papers were subjected to full text screening according to the criteria listed above.

Selected papers and data extraction

The screening identified 10 studies that met the inclusion criteria. For geographical origin, the sheet reports samples from Romania, Italy, and Germany and all the monitoring data are related to semifinished or finished samples with no reference to raw materials; other European regions are not represented in this dataset, indicating clear coverage gaps (Figure 3). In particular, the gap is even more relevant considering

that huge production of tomato from Southern European countries such as Italy and Spain.

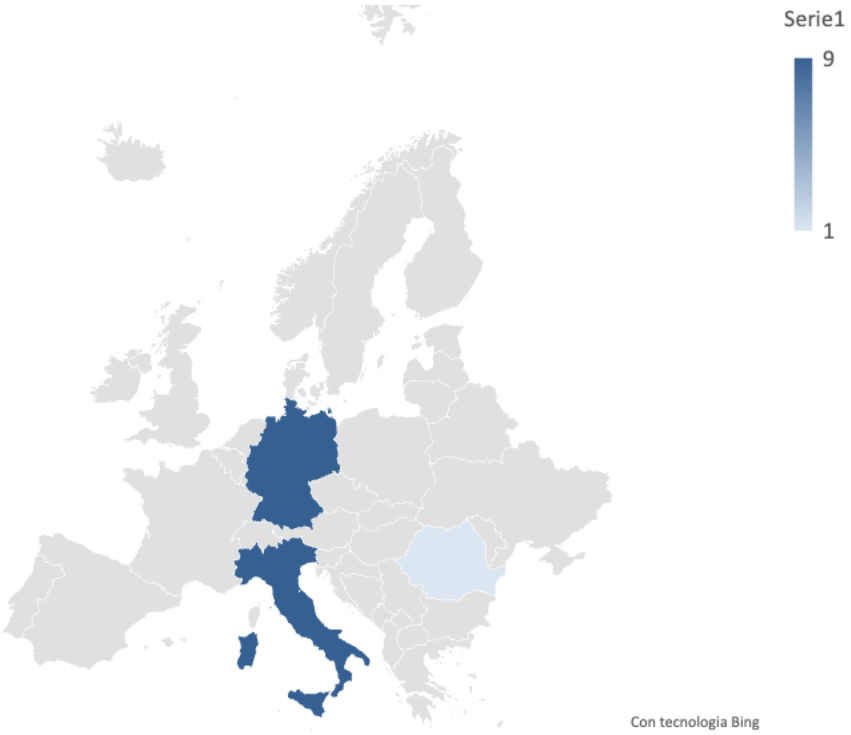

Figure 3. Geographic distribution of data collected on mycotoxin occurrence in tomato across Europe. The map uses varying shades to indicate the number of studies in each country.

The most frequently targeted analytes are TeA, AOH and AME (each listed in 7–8 entries), followed by ALT and TEN (6 entries) and ATX-1 (4 entries). DON appears only once in the analyte lists. A co-occurrence rate of about 36% is obtained, confirming that multi-toxin findings are common even within this small subset — though results are often aggregated, which limits reconstruction of sample-level co-contamination patterns.

3. Open occurrence data on food mycotoxins in the European Union: sources, structure, size, and data quality

3.1 Introduction

Understanding the occurrence of mycotoxins within European food and feed systems requires a robust, harmonised, and transparent data foundation. Numerous public, institutional, and project-based databases currently collect information on MY contamination, yet these sources differ substantially in scope, data quality, accessibility, and metadata structure. Under climate change conditions, such variability hampers accurate exposure modelling and risk prediction. This section reviews and systematises existing European data sources—including regulatory databases, scientific repositories, and research project outputs—evaluating their relevance for integration within the MYMATCH framework.

The review considered both institutional data collections (e.g., EFSA, RASFF), scientific and grey literature repositories (e.g., Zenodo, OpenAIRE), and research initiatives such as MycoCentral, AGRITOX, and HOLiFOOD, which provide valuable though heterogeneous data on MY occurrence across crops and climatic regions. Despite progress in data harmonisation, substantial gaps remain, particularly concerning metadata on environmental and agronomic variables, coverage of emerging mycotoxins, and standardisation of analytical quality criteria.

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3.2 Existing Databases on Mycotoxin Occurrence in the EU

The current European landscape for mycotoxin occurrence data is characterised by a broad but fragmented collection of information systems. These include long-standing regulatory monitoring frameworks, collaborative research initiatives, national databases, and open-access repositories. Together, they form the backbone of Europe's knowledge infrastructure for understanding contamination patterns, identifying emerging risks, and informing food safety policy. However, differences in structure, accessibility, and metadata quality across these systems continue to limit their full integration into predictive risk assessment models. This reflects the different purposes for which the database has been created. It is indeed clear that data collected with different purposes are not necessarily registered with the same format and supported by comparable metadata.

At the core of the system are the official and regulatory databases managed by EFSA, DG SANTE, and the EU Reference Laboratory (EURL) network (Table 3). These datasets represent the most harmonised and quality-assured sources available, forming the foundation of European mycotoxin surveillance. They enable consistent trend analysis and underpin regulatory decisions on exposure and maximum level setting. Despite their analytical robustness, however, gaps persist in the coverage of emerging and modified mycotoxins, as well as in the inclusion of contextual data—particularly data related to environmental, climatic, and agronomic conditions.

Complementing these regulatory data sources there are European research projects and collaborative databases that extend the scope of official monitoring (Table 4). Horizon 2020 and Horizon Europe initiatives such as *HOLiFOOD*, *MyToolBox*, and *MycoKey* have played a key role in developing integrated, multi-actor approaches to food safety. Their contributions range from compiling occurrence datasets and designing field-to-fork mitigation tools to exploring the effects of climate variables on fungal proliferation. While these projects often have limited temporal scope and fragmented outputs, they bring essential scientific innovation and contextual depth to the understanding of mycotoxin risks under climate change.

A third layer of information comes from national repositories and public portals maintained by EU Member States (Table 5). These resources vary widely in scope and transparency—from detailed annual surveillance reports in countries such as Denmark, Belgium, Austria, and Italy, to concise summaries or alert-based systems in others. National data provide valuable local insights and allow triangulation with EU-level datasets, yet differences in data formats, metadata completeness, and accessibility still hinder cross-country comparability. Strengthening harmonisation between national and EU-level data flows remains a key challenge for achieving coherent continental risk analysis.

Finally, a growing share of mycotoxin data and supporting materials is hosted in open repositories and grey-literature platforms, including *Zenodo*, *OpenAIRE*, and the *EU Open Data Portal* (Table 6). These repositories improve transparency and reproducibility by providing public access to datasets accompanying EFSA opinions, national studies, and EU-funded research outputs. However, the completeness and curation of metadata vary considerably, and documentation of data provenance is often limited. Standardising data formats and ensuring consistent metadata annotation are therefore essential steps to make these valuable resources more interoperable and reusable within broader data integration frameworks.

Taken together, these four categories of data sources demonstrate both the strength and the fragmentation of the European evidence base on mycotoxin occurrence. The official systems provide analytical reliability and continuity, while research and national datasets enrich the contextual and climatic understanding of mycotoxin risks. Open repositories ensure transparency and reusability but still require structured governance and metadata control. The integration of these diverse resources—through shared data standards, harmonised reporting protocols, and open data-sharing practices—is fundamental to achieving MYMATCH's goal of building a unified, climate-informed food safety intelligence system for the European Union.

The comprehensive mapping presented herein demonstrates the diversity of existing data ecosystems relevant to mycotoxin occurrence within the EU. While these official, research, national, and open-access sources collectively represent a valuable knowledge base, they differ substantially in structure, scope, and data quality. This heterogeneity underscores the necessity of establishing common data-quality and

metadata criteria, as foreseen in WP4 Tasks 4.1 and 4.2. The next section therefore outlines the methodological framework adopted by MYMATCH to evaluate dataset reliability, ensure comparability, and prepare harmonised inputs for subsequent modelling, risk assessment, and policy-support activities across WPs 6–10.

Repository / Platform	Host	Type of Data	Access	Strengths	Limitations
EFSA Chemical Contaminants Database (DCF/SSD2)	European Food Safety Authority (EFSA)	Harmonised occurrence data on regulated mycotoxins in food and feed, collected from EU Member States.	Restricted submission system; data summarised in EFSA opinions and scientific reports.	Standardised fields (SSD2); long-term dataset supporting risk assessments.	Gaps in metadata (climate, agronomy, storage); limited emerging mycotoxins; heterogeneity among Member States.
EFSA Knowledge Junction (Zenodo community)	EFSA / Zenodo	Deposited datasets supporting EFSA opinions (e.g., Alternaria toxins, Fusarium toxins).	Open access (CSV/XLSX).	Transparent and documented; linked to regulatory outputs.	Fragmented by opinion; variable data quality and format.
European Commission Catalogue of Mycotoxins	DG SANTE	Lists regulated and recommended mycotoxins for monitoring; references legal thresholds.	Public website (HTML).	Defines EU monitoring priorities; regulatory coherence.	Descriptive only, no quantitative data.
EURL for Mycotoxins and Plant Toxins (WFSR)	EU Reference Laboratory (Wageningen Food Safety Research)	Methods, QA/QC protocols, proficiency test (PT) results, and identification criteria for mycotoxin analysis.	Open reports and guidance PDFs.	Ensures analytical comparability and defines performance criteria.	Not a data source; provides methodological backbone only.
RASFF (Rapid Alert System for Food and Feed)	European Commission / Member States	Notifications of non-compliance (e.g., aflatoxin exceedances) in imported and EU products.	Online RASFF Portal.	Rapid, up-to-date signal of trade- and enforcement-related incidents.	Non-representative sample; unsuitable for prevalence or exposure modelling.

Table 3: Official and Regulatory Data Sources

Repository / Platform	Host	Type of Data	Access	Strengths	Limitations
HOLiFOOD (Horizon Europe)	WUR-led consortium	Integrates chemical and microbiological hazard data (including mycotoxins) for holistic food safety assessment.	Project deliverables, publications, and Zenodo repository.	Combines occurrence and exposure data under a One Health framework.	Still under construction; incomplete coverage of many mycotoxins.
MyToolBox (H2020)	University of Natural Resources and Life Sciences, Vienna (BOKU)	Field-to-fork toolbox and models for mycotoxin mitigation; includes case-study data on DON, AFB1, FUM.	Public deliverables via CORDIS and project site.	Strong link between occurrence data and mitigation strategies.	No centralised database; datasets dispersed across deliverables.
MycoKey / MycoRed (FP7–H2020)	CNR / Chinese Academy of Agricultural Sciences	Databases on *Fusarium* species, genotype–chemotype relationships, and mycotoxin risk maps.	Archived on project portals and publications.	Valuable for linking climate–pathogen–toxin relationships.	Indirect data; focused on fungal ecology rather than concentrations.
CHEFS (CompreHensive European Food Safety)	EU Open Data initiative	Aggregates ~392 million analytical results (2000–2024), including contaminants such as mycotoxins.	Open-source dataset (CSV via GitHub).	Demonstrates integration potential of multi-contaminant data.	Mycotoxin subset limited; metadata depth variable.
MycoCentral (AGRITOX)	MycoKingdom Consortium	Knowledgebase on >900 mycotoxins, metabolites, fungi, and toxicological data.	Open access (web interface).	Comprehensive compound-level data; useful for annotation.	No occurrence values; knowledge, not monitoring.

Table 4: Research and Project-Based Data Sources

Country	Authority / Institution	Public Portal or Resource	Description and Content	Access / Format
Austria	AGES; BAES	*Mykotoxine* information pages; BAES Maize Monitoring Programme	Risk factsheets and annual monitoring results for cereals (e.g., maize).	Public PDFs and annual reports; aggregated data.
Belgium	FASFC (AFSCA) / Scientific Committee	Analytical Programme and "Mycotoxins Results Overview"	Evaluation of national monitoring programme and trends (2010–2019).	PDFs and summary dashboards; historical series available.
Bulgaria	Bulgarian Food Safety Agency (BFSA)	BFSA Food Control Portal	Overview of national control activities; institutional reports.	Public portal; specific mycotoxin data limited.
Croatia	Croatian Agency for Agriculture and Food (HAPIH)	*Mycotoxins* thematic page and expert opinions	Risk information and selected survey reports.	PDFs and position papers; non-continuous data.
Cyprus	State General Laboratory (SGL)	Annual Report of SGL (Food Safety section)	Summary of official control analyses, including contaminants.	Public PDF annual report; aggregated results.
Czech Republic	State Agricultural and Food Inspection Authority (SZPI)	Official Control Portal	Laboratory activities and alerts related to mycotoxins.	Press releases and institutional pages; no structured dataset.
Denmark	Danish Veterinary and Food Administration (Fødevarestyrelsen); DTU Food	"Mycotoxins" section; Annual Surveillance Reports	Detailed surveillance data for DON, aflatoxins, and other toxins in cereals.	Annual PDF reports with tabulated data; good transparency.
Estonia	Agriculture and Food Board (PTA)	Institutional website	Information on food control organisation and accredited laboratories.	Public access; no occurrence datasets.
Finland	Finnish Food Authority (Ruokavirasto)	*Mycotoxins* risk pages	Risk information and summaries of cereal contamination levels.	Technical webpages; no downloadable data.
France	ANSES	*Mycotoxines* dossier and scientific opinions	Risk assessments, exposure summaries, and literature reviews.	Open publications; raw occurrence data submitted via EFSA.

Germany	BfR (NRL Mycotoxins & Plant Toxins)	NRL official website	Information on analytical methods, QA/QC, and EU coordination.	Technical pages; occurrence data integrated in EFSA submissions.
Greece	EFET	EFET portal and product recall alerts	National recalls and public alerts related to mycotoxins (e.g., dried fruits).	Web-based alerts; no quantitative datasets.
Ireland	Food Safety Authority of Ireland (FSAI)	*Mycotoxins* webpage and Scientific Committee reports	Regulatory framework and risk assessments.	Public PDFs; aggregated exposure information.
Italy	Ministry of Health	National Monitoring Plans on Contaminants	Annual reports on official controls and analytical results for mycotoxins.	Institutional PDFs; summary tables by commodity.
Latvia	Food and Veterinary Service (PVD)	National Food Control Portal	Official control information and alerts.	Public portal; no centralised datasets.
Lithuania	State Food and Veterinary Service (VMVT)	VMVT website	Institutional and monitoring information.	General access; no dedicated mycotoxin datasets.
Luxembourg	ALVA (Administration des Services Vétérinaires)	*Mycotoxins* information page	Hazard summaries and EFSA focal point role.	Public information sheets; non-quantitative.
Malta	Superintendence of Public Health	SPH / Environmental Health web resources	Public communications and alerts on food safety issues.	General information; no structured data.
Netherlands	NVWA / WFSR (EURL)	NRL “Mycotoxins & Plant Toxins” portal	Reference laboratory for the Netherlands and EU; monitoring and QA/QC reports.	Technical pages; downloadable reports on request.
Poland	Chief Sanitary Inspectorate (GIS)	*Ostrzeżenia* food alert section	Public warnings and recalls, including aflatoxin exceedances.	Alert-based interface; no full occurrence dataset.
Portugal	INSA; ASAE	INSA scientific publications; ASAE alerts	Occurrence data in food and infant products; alert management.	Reports and PDFs; partial quantitative results.

Romania	ANSVSA	National sampling and analysis procedures for mycotoxins	Legal and procedural documents for contaminant monitoring.	PDFs; results aggregated annually.
Slovakia	State Veterinary and Food Administration (ŠVPS SR)	Official portal and aflatoxin alerts	Regulations and summary information.	Public pages; limited numeric data.
Slovenia	UVHVVR; Agricultural Institute of Slovenia (KIS)	Official inspection portal; *Mycotoxins* technical note	Risk information and national monitoring activities.	Technical web pages; not a data repository.
Spain	AESAN	Scientific Committee opinions and thematic reports	Reviews on mycotoxins and climate–food safety links.	Open access PDFs; aggregated data only.
Sweden	Swedish Food Agency (Livsmedelsverket)	*Mögelgifter/Mykotoxiner* portal; national NRL	Technical guidance and summaries of national control activities.	Informative pages; non-tabulated results.

Table 5: Publicly available national repositories and portals on mycotoxin occurrence in EU Member States

Repository / Platform	Host	Type of Data	Access	Strengths	Limitations
Zenodo & OpenAIRE	CERN / EU OpenAIRE	Datasets from EU projects and publications (CSV, XLSX).	Open access.	Easy discovery of project-level data (EFSA KJ, MyToolBox, HOLiFOOD).	Inconsistent formats and metadata; QA/QC not guaranteed.
Data.europa.eu (EU Open Data Portal)	EU Commission	Historic EFSA datasets and research outputs (e.g., Alternaria toxins dataset).	Open access.	Transparent and citable; harmonised metadata.	Partial coverage; older datasets may lack SSD2 alignment.

Table 6: Grey Literature and Open Science Repositories

3.3 5. Data Quality and Stewardship in Mycotoxin Occurrence Data

The European system for monitoring and researching mycotoxins produces an impressive volume of analytical results every year. However, the value of these data for food safety and climate-change risk assessment depends less on analytical precision—already ensured through EU laboratory standards—and more on how the information is collected, curated, structured, and shared. Data stewardship is therefore the decisive factor determining whether existing evidence can be reused, compared, and modelled effectively.

3.3.1 Overview of the Current Data Landscape

The European evidence base on mycotoxin occurrence is extensive but fragmented, encompassing regulatory datasets, national monitoring programmes, research project outputs, open repositories, and a large corpus of scientific literature. These diverse sources differ in structure, accessibility, and documentation, leading to marked variability in data quality and reusability.

At the regulatory level, the *EFSA Chemical Contaminants Database* and its *Data Collection Framework (DCF)* remain the centralised system for harmonised reporting across Member States. Data submitted under the *Standard Sample Description (SSD2)* template are the most structured and traceable currently available. Nonetheless, the extent of metadata reporting varies across the database; optional fields on sampling context, climate, or storage conditions are often left incomplete, limiting downstream analyses. It should be noted that monitoring data are meant as a support for exposure assessment, which is unrelated to climate analysis. Therefore, the lack of proper geographical information should not be regarded as a scientific limitation, but mainly as a structural gap in data re-usability.

The EU Reference Laboratory (EURL) for Mycotoxins and Plant Toxins and the associated National Reference Laboratories (NRLs) ensure analytical comparability across the Union through method validation and proficiency testing. However, their outputs—typically aggregated proficiency data or summary reports—are not stored as machine-readable occurrence datasets.

Beyond regulatory surveillance, several EU-funded research projects (e.g., *MyToolBox*, *MycoKey*, *HOLiFOOD*) have generated valuable datasets linking fungal ecology, crop

management, and environmental factors to contamination levels. Yet these data are usually isolated within project deliverables, often lacking persistent identifiers or standardised metadata.

National repositories vary widely. A few Member States publish annual quantitative results, while most release only aggregated statistics or qualitative summaries. Data formats range from spreadsheets to PDFs, with inconsistent variable naming and little information on sampling or climate context.

Finally, the scientific literature constitutes a vast but unevenly structured source of occurrence information. Numerous studies report contamination levels in specific commodities, regions, or seasons. However, these data are rarely deposited in open repositories and are typically presented as aggregated summaries—mean concentrations, ranges, or percentages of positive samples—rather than raw, record-level values. Geographical traceability is often limited to broad regional labels (e.g., "Southern Europe"), and methodological details such as sampling design, LOD/LOQ values, or sample size are inconsistently documented. Furthermore, a pronounced publication bias exists: studies tend to report non-compliant or unusually high concentrations, while negative or compliant results remain unpublished. This bias distorts apparent contamination distributions and complicates quantitative modelling or meta-analysis.

As a result, while Europe collectively generates a vast amount of mycotoxin data, the absence of coordinated stewardship, standardised metadata, and open, record-level accessibility severely limits its potential for integration and long-term reuse and careful examinations of the sampling and analysis procedure is necessary to ensure that the data for each reported data collection is compliant with the need for the purpose of reuse of data.

3.3.2 5.2 Main Weaknesses, Limitations, and Gaps

Despite this abundance of data, several systemic weaknesses limit its scientific and regulatory value:

Fragmentation and heterogeneity - The coexistence of multiple data streams—regulatory, research, and national—without shared governance or technical alignment

results in duplication and loss of coherence. Aggregated tables cannot be readily combined with record-level datasets, and even harmonised systems like EFSA's DCF receive submissions of uneven completeness.

Metadata and contextual gaps - Critical contextual fields such as crop variety, harvest year, meteorological conditions and geolocalization are rarely reported. This omission prevents correlation of mycotoxin occurrence with climatic or agronomic factors, restricting the development of predictive or climate-sensitive models.

Lack of interoperability and discoverability - Different data formats (Excel sheets, PDFs, databases, dashboards) and missing persistent identifiers make automatic integration impossible. Few datasets provide APIs or machine-readable metadata, reducing their accessibility for data-driven analysis.

Limited traceability and version control - Many datasets lack clear provenance information—such as source institution, version number, or curation history—compromising reproducibility. Without proper documentation, even high-quality analytical data lose credibility over time.

Scarcity of co-occurrence data and emerging toxins - Monitoring programmes generally focus on single toxins and when several toxins are included, they are rarely reported on single samples. Consequently, datasets describing multiple mycotoxins in the same sample are rare. Modified and emerging compounds (e.g., DON-3-glucoside, Alternaria toxins) remain under-represented or reported below quantification limits, leading to left-censored data distributions.

Restricted accessibility - While open data policies have advanced, many Member States still treat occurrence data as internal. Reports are often publicly available only in aggregate form, with record-level results inaccessible due to confidentiality or administrative barriers.

Collectively, these limitations prevent the creation of a coherent European knowledge base suitable for high-resolution exposure assessment and predictive modelling.

5.3 Criteria for Data Acceptance

To address these issues, datasets intended for integration into European-level analyses should meet explicit data-acceptance criteria focusing on stewardship rather than analytical performance. The dimensions useful to define minimal requirements for acceptance are reported in the following table.

Dimension	Acceptance Criteria	Indicators
Provenance	Clear identification of data owner, curator, and collection purpose.	≥95 % of records include source institution and data-collection rationale.
Structure	Dataset structured in SSD2 or equivalent machine-readable format.	100 % compliance with standard field names and data types.
Metadata completeness	Presence of essential fields: FoodEx2 code, date, location, result, LOD/LOQ.	≥90 % of mandatory fields populated; ≤5 % missing values per field.
Traceability	Unique identifiers for samples/datasets; documented version control.	All datasets assigned DOI/UUID; complete version history available.
Interoperability	Use of controlled vocabularies and standard units.	Harmonised FoodEx2 and toxin codes across all submissions.
Accessibility	Data or metadata publicly accessible with licence and contact point.	≥80 % of datasets discoverable via open repository or catalogue.
Reusability	Clear licence (CC-BY or equivalent) and FAIR compliance statement.	≥70 % datasets explicitly FAIR-compliant or with reuse conditions defined.

Table 7: Data-Quality Criteria

Datasets meeting these criteria are considered *fit for purpose* for inclusion in risk assessment and modelling frameworks. Those falling short may still inform qualitative analyses but require harmonisation or metadata enrichment before quantitative use. The review of Europe's current mycotoxin data landscape highlights that the primary obstacles to effective risk assessment lie in the fragmentation, poor interoperability, and limited transparency of existing data systems rather than in analytical precision.

4. Knowledge about rapid methods for mycotoxin analysis

Rapid mycotoxin detection techniques have progressed significantly to complement conventional chromatographic methods such as HPLC–FLD and LC-MS/MS, the latter still regarded as the regulatory reference because of its sensitivity, selectivity, and multi-analyte capability [Nolan et al. 2019; Tittlemaier et al. 2025]. Technological improvements, including UPLC, simplified extraction, and faster analytical runs [Sulyok et al. 2024], have increased throughput, yet LC-MS/MS remains expensive, time-consuming, and dependent on expert operation. These constraints have encouraged the development of faster and more affordable alternatives for field or industrial screening (Tittlemaier et al. 2025).

New methods fall into five major families.

Immunoassay-based techniques such as ELISA, lateral-flow devices (LFDs), immunochromatographic strips, and fluorescence-based assays—are the most widely adopted (Wang et al. 2022; Zhou et al. 2020). They offer simplicity and low cost, providing results in minutes for regulated toxins such as AFB1, DON, ZEA, OTA, and FB1. Recent LFDs, enhanced with nanomaterials or smartphone readers, allow multiplex detection and improved visual clarity.

Biosensors and aptasensors combine selective biorecognition (antibodies, aptamers, or molecularly imprinted polymers) with electrochemical or optical transducers. Carbon-nanotube and graphene-based platforms achieve detection limits comparable to LC-MS/MS and show promise for portable multi-analyte monitoring [Nolan et al. 2019; Zhou et al 2020; Tittlemeier et al. 2025].

Spectroscopic techniques—near- and mid-infrared (NIR, MIR), FT-NIR, and Raman spectroscopy—provide reagent-free, non-destructive analysis (Shekar et al. 2025). Chemometric and machine-learning models [Kos et al. 2016] enhance discrimination between contaminated and clean samples. Surface-enhanced Raman scattering (SERS) further improves sensitivity by amplifying signals with metal nanoparticles [Logan et al. 2024].

Mass-spectrometry-based screening using ambient-ionisation or portable MS systems delivers in-situ measurements with minimal sample preparation, though cost

and standardisation limit routine use (Busman & Maragos 2015; Geballa-Koukoula et al. 2021).

Finally, **emerging digital platforms** such as lab-on-a-chip devices, microfluidics, electronic noses, and smartphone-integrated sensors aim to automate detection, offering high-throughput, field-deployable solutions (Geballa-Koukoula et al. 2021; Kasputis et al. 2024; Yin et al. 2025).

A structured literature review following the PRISMA approach identified and compared these five categories across key commodities (wheat, maize, tomato). The collected literature was systematised through Zotero and stored in the MYMATCH repository. A scientific paper is under preparation to make the results available to the scientific community.

Quantitative indicators—sensitivity, reproducibility, and throughput—were analysed to highlight trade-offs between analytical robustness and practicality, particularly for integration with LC-MS/MS workflows.

For cereals, most progress concerns rapid tools targeting *Aspergillus*- and *Fusarium*-derived toxins. LFDs and multiplex immunoassays now permit simultaneous detection of several analytes, while electrochemical biosensors achieve sub-ppb limits with enhanced portability. Spectroscopic and SERS systems enable non-invasive screening during milling or storage. In tomato products, where pigments and acids complicate analysis, lateral-flow and enzyme-immunoassays for Alternaria toxins (TeA, AOH, AME, ALT, TEN) demonstrate results within 15–20 min and recoveries comparable to UHPLC-MS/MS [Gonçalves et al. 2022, Cai et al. 2022, Liang et al. 2021, Gross et al. 2011]. Although validation on naturally contaminated samples remains limited, rapid assays continue to improve in reliability.

Overall, rapid mycotoxin detection technologies now complement conventional LC-MS/MS by enabling early identification of contaminated batches, reducing confirmatory workload, and enhancing the responsiveness of food-safety monitoring systems.

4.1 Overall Trends and Knowledge Gaps

Rapid detection technologies for mycotoxins have evolved into **a multi-platform ecosystem** bridging laboratory accuracy and field applicability. Immunochemical methods dominate commercial use; biosensors and aptasensors push the frontier of

sensitivity and miniaturisation; spectroscopy and portable MS offer reagent-free, high-throughput alternatives.

Nevertheless, persistent limitations include:

- Incomplete validation on naturally contaminated samples and restricted inter-laboratory comparability;
- Limited multi-mycotoxin capability (typically ≤ 3 targets);
- Variable robustness across complex matrices such as tomato concentrates; and
- Lack of harmonised performance criteria for screening versus confirmatory use.

The continuous integration of nanomaterials, microfluidics, and AI-based data processing is expected to enhance analytical precision while reducing costs and sample-handling requirements. In parallel, coupling these rapid tools with harmonised data-collection frameworks will strengthen the European capacity to generate **high-quality, traceable occurrence data**—a prerequisite for accurate exposure modelling and climate-related risk assessment.

Concluding remarks

Deliverable D4.1 has established the scientific and methodological foundations for MYMATCH by consolidating existing knowledge, data sources, and analytical approaches concerning the ecology, occurrence, and detection of mycotoxins under climate-change conditions. The review demonstrates that while the European research and regulatory landscape has produced a remarkable volume of analytical and ecological data, its full potential remains underexploited due to fragmentation, inconsistent metadata, and limited interoperability among datasets.

Across all crops investigated—maize, wheat, and tomato—data on fungal ecology and mycotoxin occurrence are abundant but unevenly distributed. Maize and wheat are supported by relatively extensive surveillance and literature, whereas tomato still lack robust, quantitative datasets suitable for predictive modelling. In addition, most published data remain aggregated, hindering their integration into dynamic exposure or risk-assessment frameworks that can account for climatic variables.

From a methodological perspective, the deliverable highlights major advances in analytical capacity, including high-throughput LC-MS/MS and the emergence of rapid, on-site screening methods such as biosensors, lateral-flow assays, and spectroscopic techniques. These innovations enhance responsiveness across the food chain but require harmonised validation protocols and standardised performance criteria to ensure comparability and regulatory acceptance.

The comprehensive mapping of European repositories—spanning EFSA databases, national monitoring programmes, and open-science platforms—reveals a clear need for improved data stewardship. Implementing FAIR principles, adopting harmonised metadata standards (e.g., SSD2, FoodEx2), and ensuring persistent identifiers will be crucial to enable long-term interoperability and reuse. These actions form the backbone of a modernised European food-safety data ecosystem capable of supporting climate-responsive predictive models.

In summary, D4.1 provides both a diagnosis and a roadmap: Europe possesses the analytical expertise and the scientific evidence to monitor mycotoxins effectively, but the infrastructure for sharing, linking, and reusing this information requires systematic strengthening. The insights and recommendations presented here will guide subsequent MYMATCH work packages in generating guidelines for a rationale data

collection; new, high-quality datasets that can include in the future input from reliable institutions able to properly collect data and metadata; developing predictive tools; and translating scientific advances into policy and risk-management strategies.

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