Advanced analytical methods for chemical foodborne hazards

Rudolf Krska
G. Salentijn, Ids Lemmink, A. Schamann, M. Suman
+ FoodSafeR consortium

22 Members of the FoodSafeR Advisory Board representing EU and global multi-actors:

.....eminent outreach is given through an ***international Advisory Board spanning global dimensions, which will also serve as hubs for the FoodSafeR to anticipate and mitigate future food crises.***

frontiers | Frontiers in Sustainable Food Systems

TYPE Conceptual Analysis
PUBLISHED 07 October 2025
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A FoodSafeR perspective on emerging food safety hazards and associated risks

John F. Leslie[1], Chibundu N. Ezekiel[2], Martin Wagner[3,4], Chris Elliott[5], Oonagh McNerney[6], Mieke Uyttendaele[7], Wu Yongning[8], Songxue Wang[9], Sheila Okoth[10], James Lindsay[11], Dorothea F. K. Rawn[12], Sheot Harn Chan[13], Kai Zhang[14], Veronica M. T. Lattanzio[15], Felicia Wu[16], Ranajit Bandyopadhyay[17], Eleonora Dupouy[18], Steve Wearne[19], Samuel Godefroy[20,21], Michele Suman[22] and Rudolf Krska[2,23]*

OPEN ACCESS

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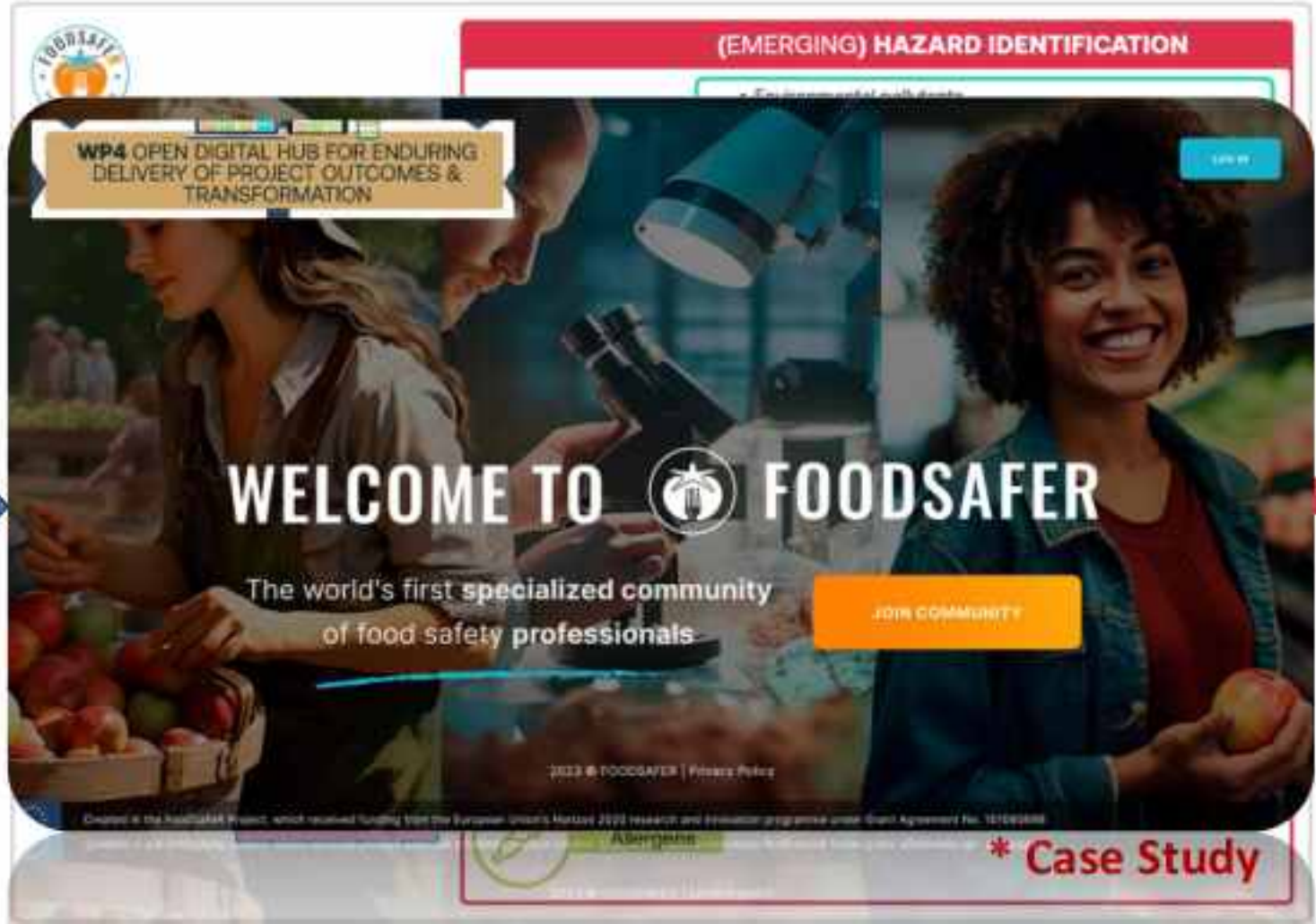
*CORRESPONDENCE
Rudolf Krska

TABLE 1 Food safety hazards discussed at the FoodSafeR workshop.

Type of risk	Risk agent	
	Natural toxins	Mycotoxins (e.g., *Aspergillus* toxins including aflatoxins and ochratoxin A, ergot alkaloids, and *Fusarium* toxins including deoxynivalenol, fumonisins, T-2, HT-2 and zearalenone), phycotoxins (e.g., ciguatera toxins), plant toxins (e.g., pyrrolizidine alkaloids and tropane alkaloids)
	Toxic elements	Arsenic, cadmium, lead, mercury and other heavy metals
	Chemicals	Allergens, bisphenol A, drug residues, environmental inhibitors, ethylene oxide, flame retardants, food additives, food processing contaminants (e.g., acrylamide), micro- and nano-plastics, mineral oils, plasticizers, per- and polyfluoroalkyl substances (PFAS), perfluorooctane sulfonate *(PFOS)*, persistent organic pollutants (e.g., dioxins), pesticide residues (e.g., fipronil and neonicotinoids), and volcanic ashfall

Identification & managing emerging hazards/risks: **digital hub**

FoodSafer Framework



Other relevant case studies in Chemical hazard/risk emergence

- **Combatting illegal addition of toxic chemicals:** case **lead chromate** and metanil yellow dye in **turmeric** using portable spectroscopy devices
- **Advanced mycotoxin monitoring** in view of climate change and improved **prediction tools**

- **Reduction** of **furans** and **mycotoxins** through mechanical & thermal processing at industrial scale
- Advancing **(bio)analytical sensing** and diagnostic tools, for the on-site testing of
  - **pyrrollizidine alkaloids** (21 regulated) in herbal teas
  - **tropane alkaloids** in cereals

WP3 CHEMICAL HAZARDS AND ASSOCIATED RISKS EMERGENCE

Drivers of (emerging) food safety hazards/risks

based on participatory workshop with stakholders, interviews and International Advisory Board (in STEEP categories)

Social Drivers

Consumer behaviour:
- gluten free, high fibre, ...

Environmental Drivers

Environmental contamination:
- Pesticides, heavy metals
- Bioaccumulation of toxins

Technological Drivers

Technologies in food production:
- Novel food sources (insects)
- Thermal degradation of toxins

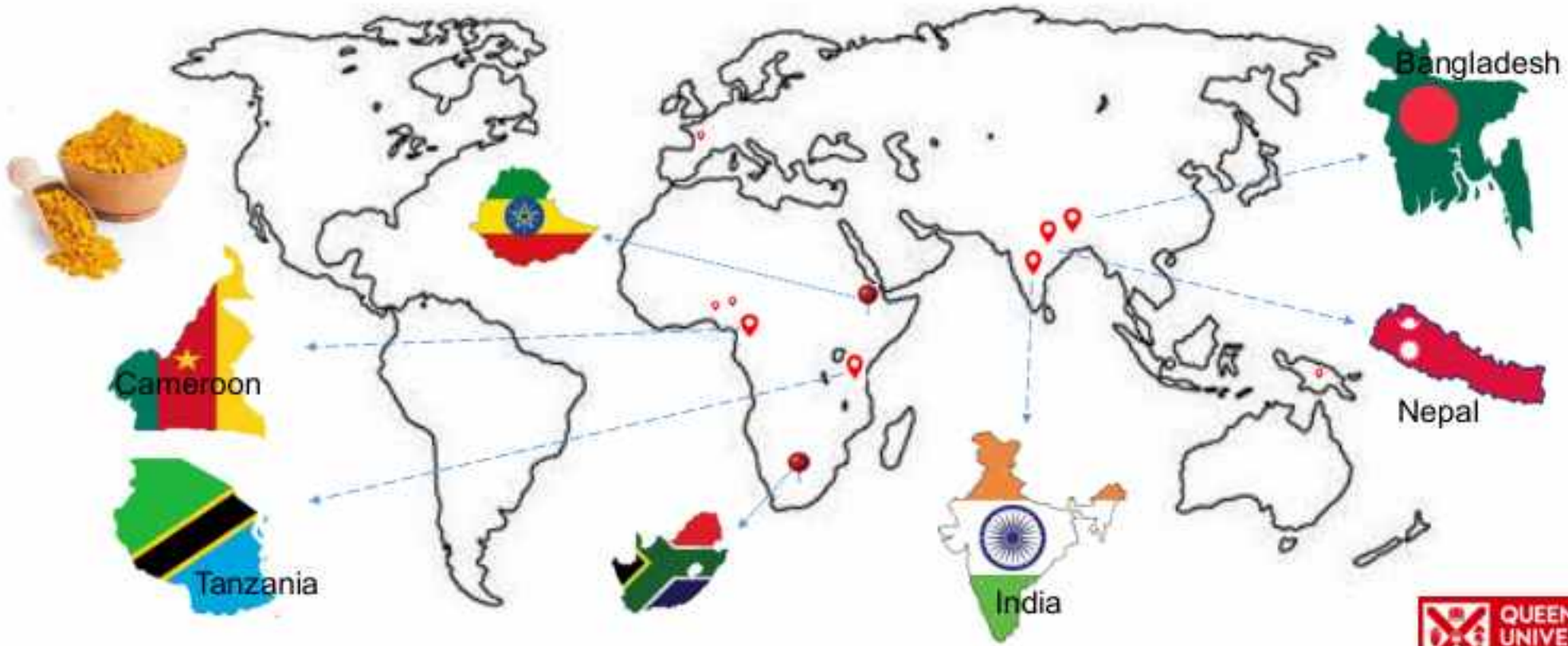
Political Drivers

Legislation, policies and governance:
- Food safety monitoring (RASFF)

Economic Driver

Distribution:
- Food fraud, Authenticity
- Proper Storage

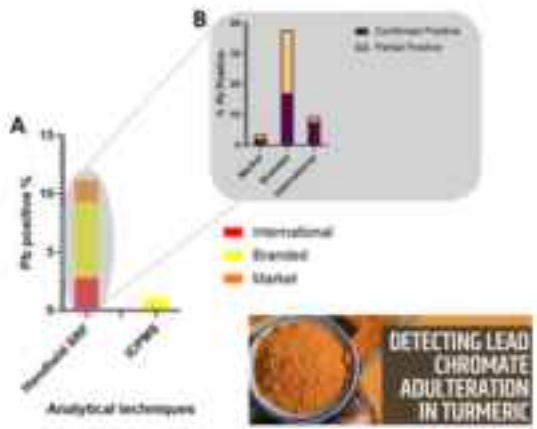
Illegal addition of toxic chemicals to food: the turmeric - lead chromate case - sources & emerging markets of a popular spice



QUEEN'S UNIVERSITY BELFAST

Food fraud: Combatting the illegal addition of toxic chemicals to food: the tumeric-lead chromate case.

- **Turmeric** = spice with numerous claimed health benefits => addition of **lead chromate** and **metanil** to give it a more vibrant yellow colour
- **Portable spectroscopy devices** e.g. NIR, FTIR, Hyperspectral imaginer, coupled with chemometrics and AI and XRF devices



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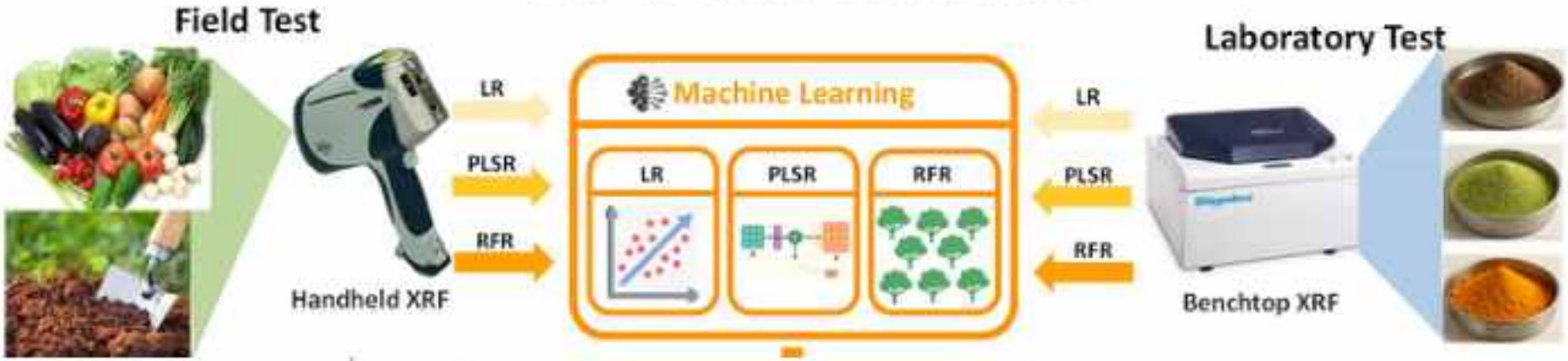
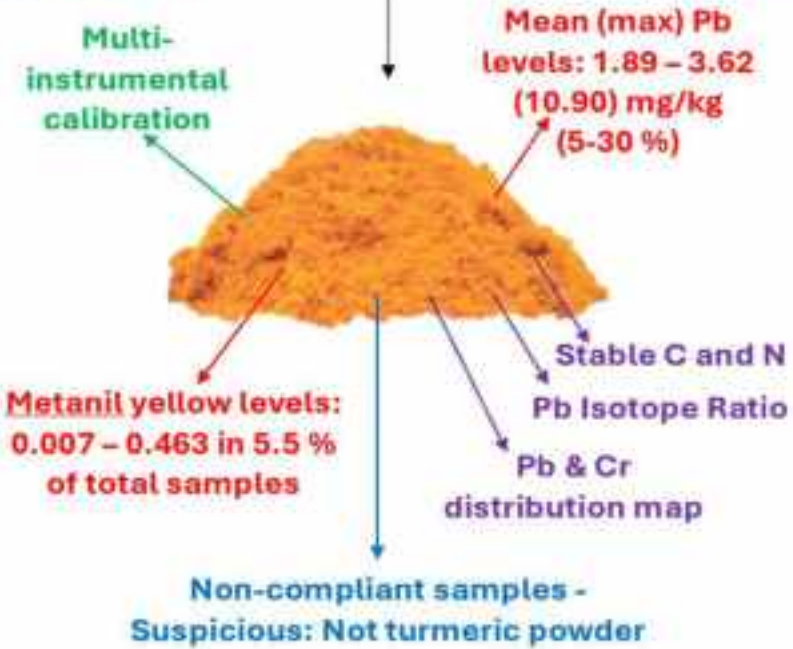
Paul William et al., IGFS

Multi-elemental Measurement





Paul William et al., IGFS, QUB

Drivers of (emerging) food safety hazards/risks

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- Proper Storage

- From both, a **food systems** and a **hazard analysis** perspective
- In total: 39 subdrivers

Liesbeth Jacxsens, U Ghent, 2025

EU Rapid Alert System for Food and Feed (RASFF)

Recent RASFF notifications by food hazard category

- mycotoxins = the **third** most notified hazard (401)
- **notifications mainly** concerned aflatoxins (331)
- **most common** product category: nuts, nut products, seeds (226)
- most reported origin: US (85)

https://food.ec.europa.eu/document/download/911d49f2-b3ef-4752-8ea3-5f20dbbe9945_en?filename=acn_annual-report_2023.pdf

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Listen

Reviews

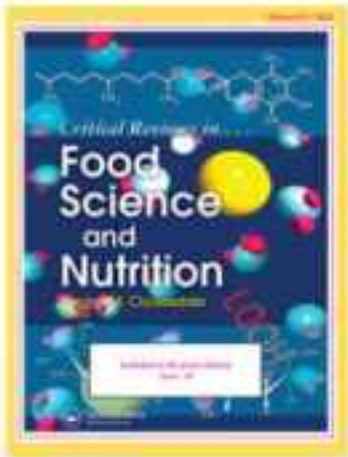
Worldwide contamination of food-crops with mycotoxins: Validity of the widely cited 'FAO estimate' of 25%

Mari Eskola, Gregor Kos, Christopher T. Elliott, Jana Hajšlová, Sultan Mayar & Rudolf Krska

Pages 2773-2789 | Published online: 03 Sep 2019

Download citation https://doi.org/10.1080/10408398.2019.1658570

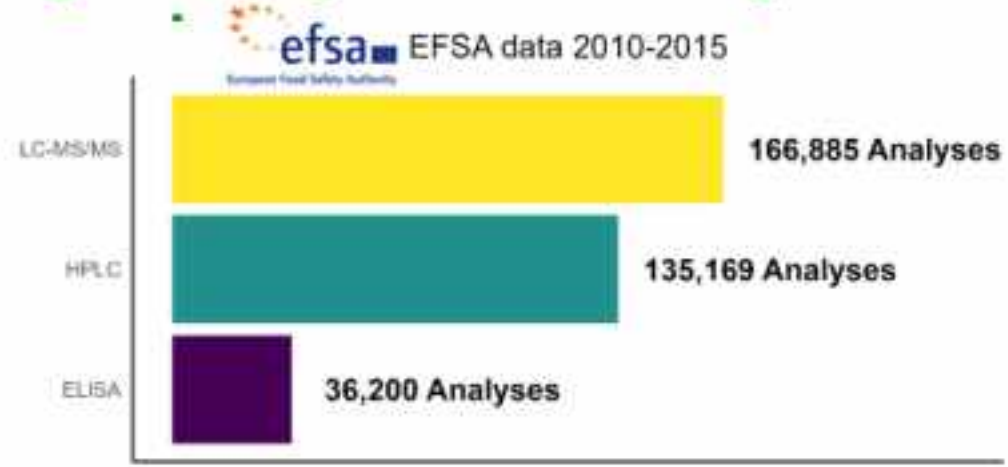
Based on **EFSA** data from **175.000 food samples** & **Biomin** data from **1.900 feed samples**

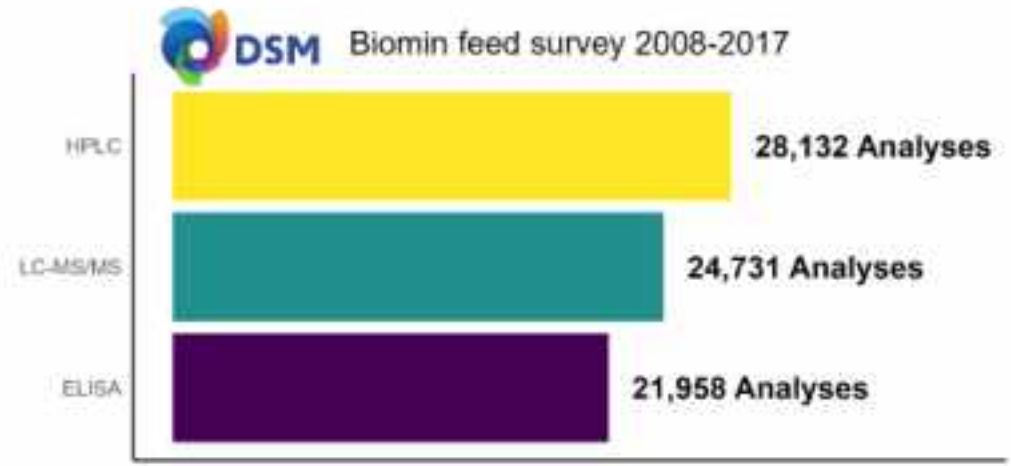


Current mycotoxin occurrence above the EU and ***Codex limits confirm the FAO 25% estimate****, while this figure* ***greatly underestimates the occurrence above the detectable levels of*** *(up to 80%)****.*** *The high occurrence is likely explained by a combination of the* ***improved sensitivity of analytical methods*** *& impact of climate change.*

BOKU UNIVERSITY

Targeted mycotoxin analysis – employed routine





Eskola et al., 2020; Worldwide contamination of food-crops with mycotoxins: Validity of the widely cited 'FAO estimate' of 25
Gruber-Dorninger et.al., 2019; Global Mycotoxin Occurrence in Feed: A Ten-Year Survey

REVIEW

ADVANCED MATERIALS
www.advmat.de

PHOTON FOOD

Advancing Mycotoxin Detection in Food and Feed: Novel Insights from Surface-Enhanced Raman Spectroscopy (SERS)

Natasha Logan, Cuong Cao, Stephan Freitag, Simon A. Haughey, Rudolf Krska, and Christopher T. Elliott*

WAGENINGEN UNIVERSITY & RESEARCH

Received: 19 May 2022 | Revised: 18 August 2022 | Accepted: 6 September 2022

DOI: 10.1111/1541-4337.13054

COMPREHENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY

Comprehensive REVIEWS WILEY

FFoQSI

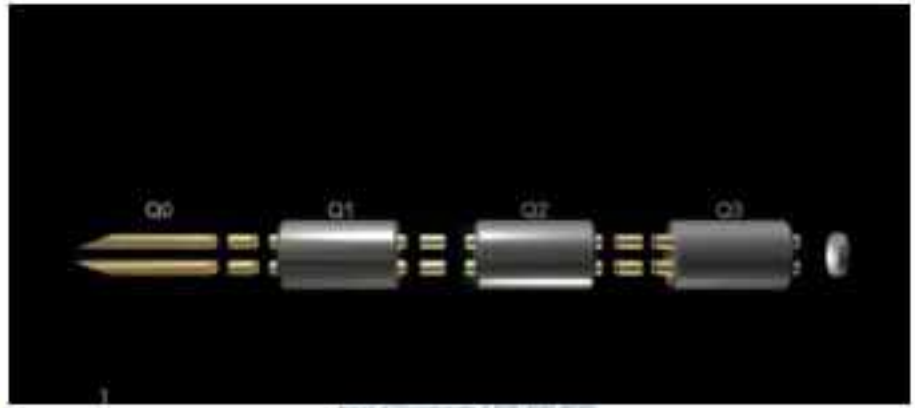
QUEEN'S UNIVERSITY BELFAST

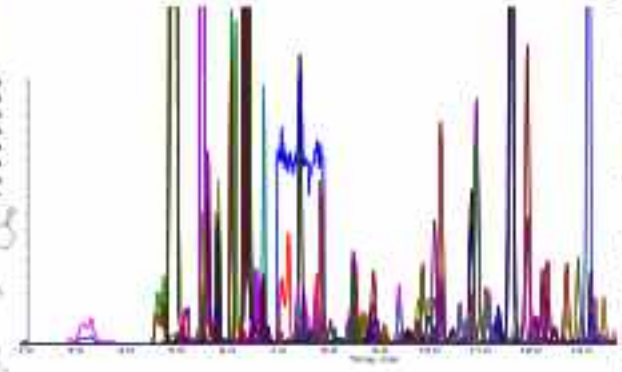
The potential and applicability of infrared spectroscopic methods for the rapid screening and routine analysis of mycotoxins in food crops

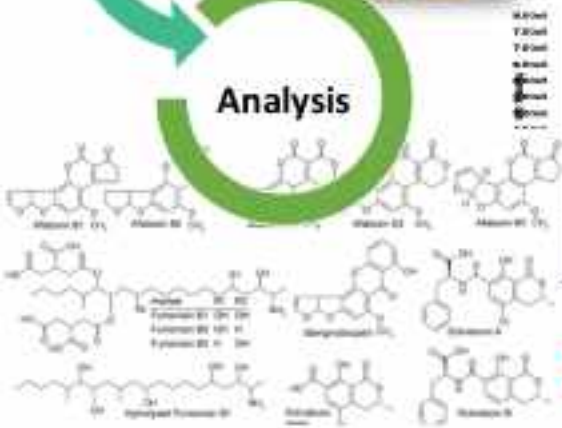
Stephan Freitag[1,2] | **Michael Sulyok**[1,2] | **Natasha Logan**[3] | **Christopher T. Elliott**[3] | **Rudolf Krska**[1,2,3]

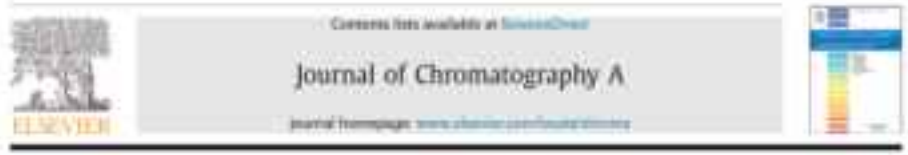
Multi-Class-Analysis by LC-MS/MS:

Dilute & shoot for 500 mycotoxins









Journal of Chromatography A

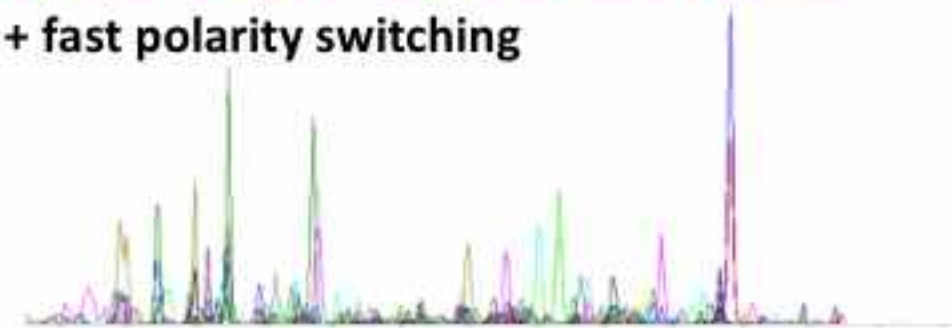
Realizing the simultaneous liquid chromatography-tandem mass spectrometry based quantification of >1200 biotoxins, pesticides and veterinary drugs in complex feed

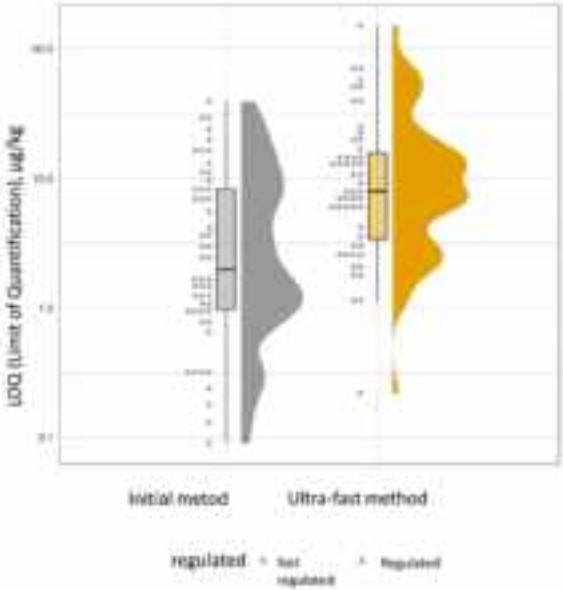
David Steiner[a], Michael Sulyok[b,*], Alexandra Malachová[a], Anneliese Mueller[a], Rudolf Krska[b,c]

>1.200 contaminants in 45 min

Accelerating multi-toxin LC-MS/MS

UHPLC + fast polarity switching





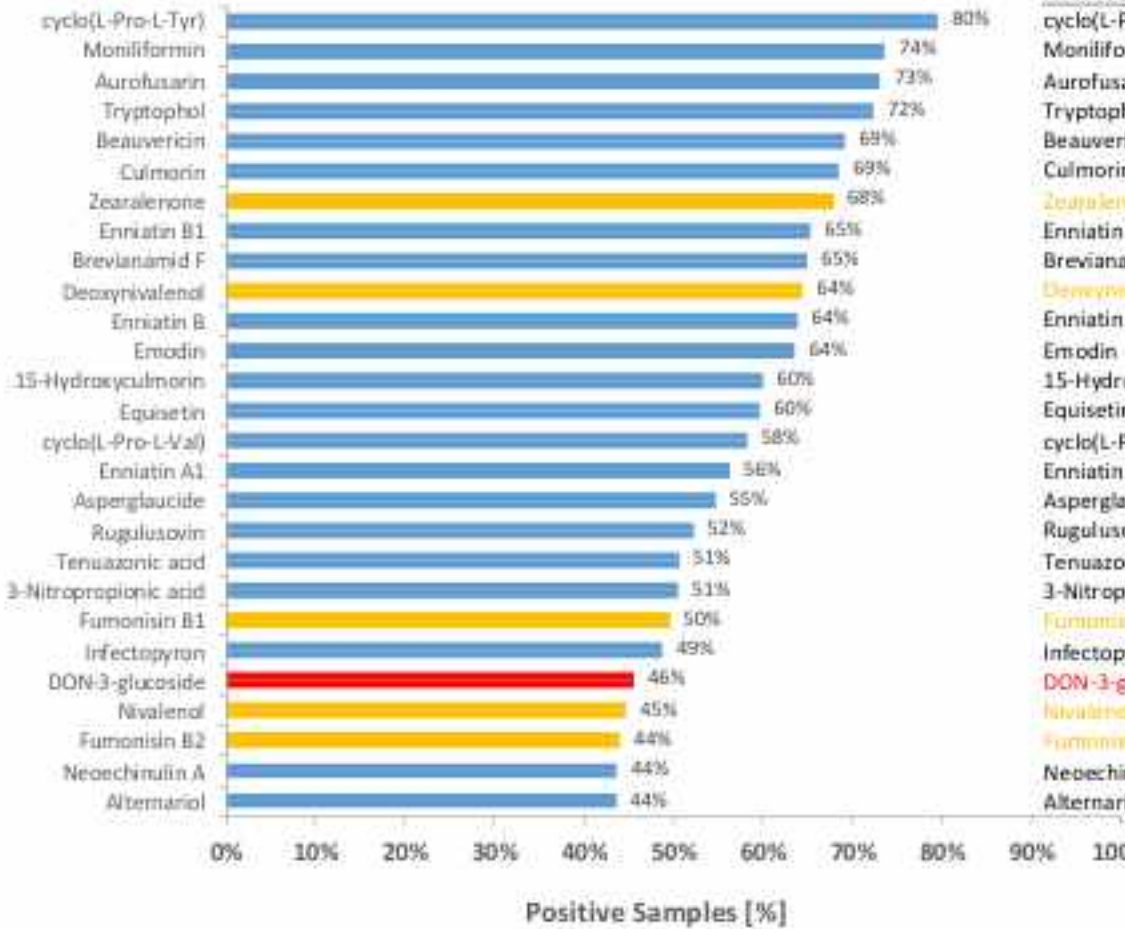
- **Quantification of 931 secondary metabolites in 11 min**
- **LOQ$_{AFB1}$: 1.7 µg/kg**

Journal of Food Composition and Analysis
Volume 151, March 2026, 108408

Exploring the limits of UHPLC-MS/MS with polarity switching towards the quantification of 931 mycotoxins and other secondary metabolites in cereal-based food

Lidija Kenjeric [b], Michael Sulyok [b], Christoph Bueschl [b], Alexandra Malachova [c], Rudolf Krska [b,c]

4.300 samples analysed with a multi-mycotoxin approach

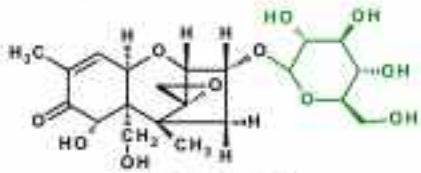


Metabolite	Average [µg/kg]	Maximum [µg/kg]	Rank
cyclo(L-Pro-L-Tyr)	**632**	34,910	1
Moniliformin	**95**	2,900	2
Aurofusarin	**954**	319,920	3
Tryptophol	**392**	39,190	4
Beauvericin	**28**	1,610	5
Culmorin	**525**	157,114	6
Zearalenone	108	11,192	7
Enniatin B1	**55**	5,507	8
Brevianamid F	**89**	2,614	9
Deoxynivalenol	610	**34,861**	10
Enniatin B	**53**	7,519	11
Emodin	**57**	4,155	12
15-Hydroxyculmorin	**419**	19,320	13
Equisetin	**34**	2,081	14
cyclo(L-Pro-L-Val)	**1,016**	30,360	15
Enniatin A1	**23**	2,063	16
Asperglaucide	**124**	22,566	17
Rugulusovin	**77**	1,658	18
Tenuazonic acid	**203**	8,115	19
3-Nitropropionic acid	**25**	4,068	20
Fumonisin B1	791	111,253	21
Infectopyron	**1,091**	101,408	22
DON-3-glucoside	**89**	4,516	23
Nivalenol	104	11,232	24
Fumonisin B2	305	35,213	25
Neoechinulin A	**87**	14,320	26
Alternariol	**15**	1,458	27

(Identification of) **emerging** hazards and associated risks

Emerging risk definition (EFSA)

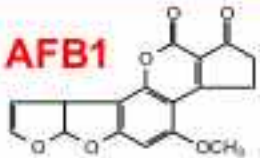
New identified hazard + Significant exposure



DON-3-Gluc

Known hazard + New significant exposure

AFB1



Known hazard + Decreased or Increased host susceptibility + Significant exposure

Emerging Mycotoxins

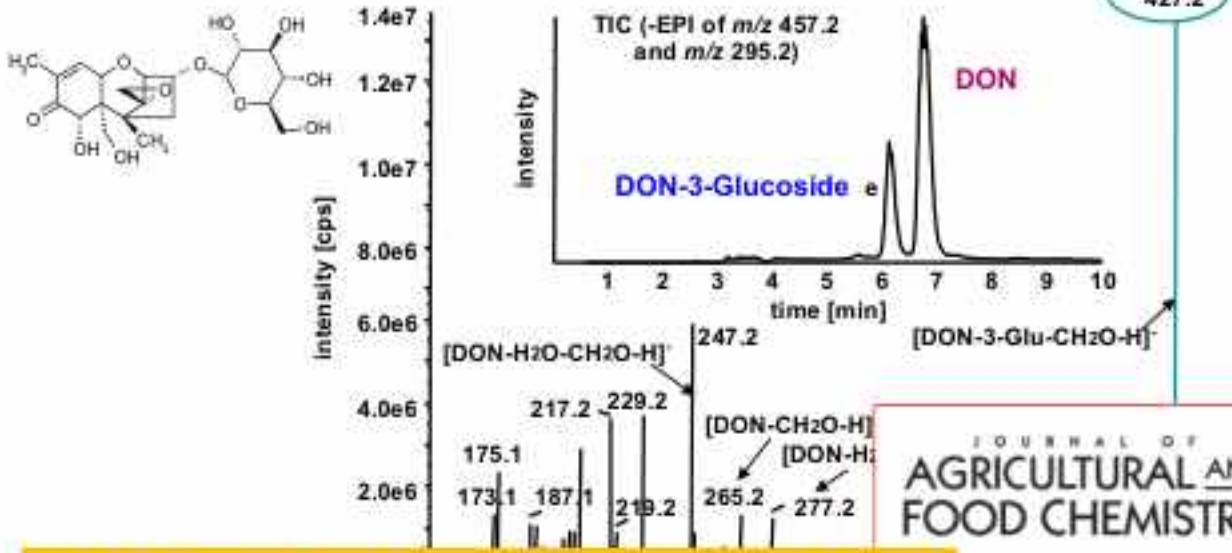
Advanced LC-MS methods

New findings (e.g. masked toxins)

More frequent and new/unexpected occurrence data

Climate change → Plant breeding

First report on the natural occurrence of conjugated (masked) DON in wheat (2005)



427.2

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

J. Agric. Food Chem. 2005, 53, 3421−3425 3421

EFSA conclusion, 2024: Group-TDI of 1 µg/kg bw per day for the sum of DON, 3-Ac-DON, 15-Ac-DON and **DON-3-glucoside.**

Masked Mycotoxins: Determination of a Deoxynivalenol Glucoside in Artificially and Naturally Contaminated Wheat by Liquid Chromatography−Tandem Mass Spectrometry

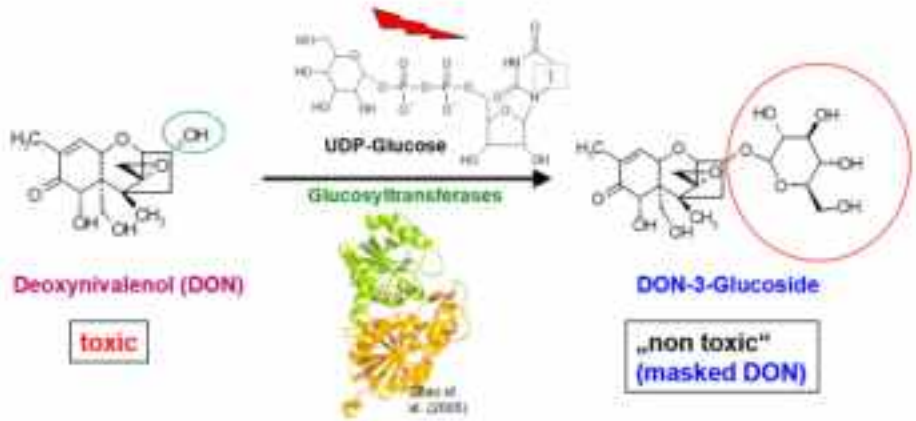
Franz Berthiller,† Chiara Dall'Asta,† Rainer Schuhmacher,*,† Marc Lemmens,‡ Gerhard Adam,§ and Rudolf Krska†

Journal of Experimental Botany, Vol. 00, No. 0 pp. 1–15, 2026
https://doi.org/10.1093/jxb/erag156 Advance Access Publication 28 March 2026

RESEARCH PAPER

Culmorin inhibits detoxification of the mycotoxin deoxynivalenol by plant UDP-glucosyltransferases

Herbert Michlmayr[1,2,*], Gerlinde Wiesenberger[1,2], Katrin Rehak[1], Marta Sopel[3,†], Kristina Funtak[1], Alexandra Malachová[3,4], Philipp Fruhmann[5,‡], Julia Weber[5,§], Marie Dufresne[6], Rudolf Krska[3,7], Franz Berthiller[3], and Gerhard Adam[1]



Archives of Toxicology (2019) 93:1729–1743
https://doi.org/10.1007/s00204-019-02459-w

BIOLOGICS

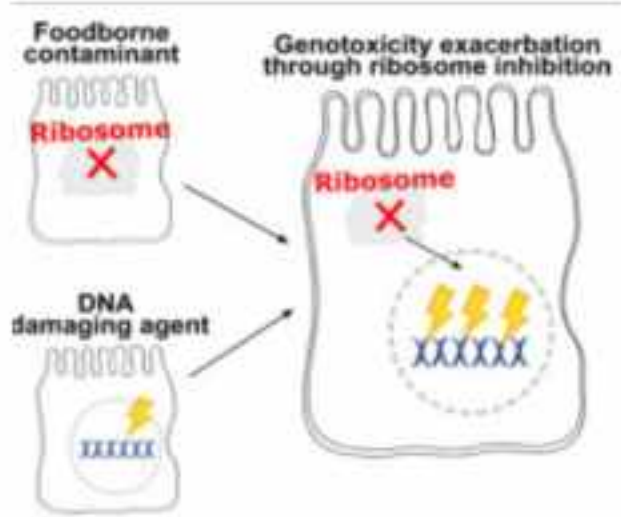
The *Fusarium* metabolite culmorin suppresses the in vitro glucuronidation of deoxynivalenol

Lydia Woelflingseder[1] · Benedikt Warth[1] · Immina Vierheilig[1] · Heidi Schwartz-Zimmermann[2] · Christian Hametner[3] · Veronika Nagl[4] · Barbara Novak[4] · Bojan Šarkanj[5] · Franz Berthiller[2] · Gerhard Adam[6] · Doris Marko[1]

Science of The Total Environment
Volume 820, 10 May 2022, 153280

The foodborne contaminant deoxynivalenol exacerbates DNA damage caused by a broad spectrum of genotoxic agents

Marion Garofalo [a b], Delphine Payros [b], Eric Oswald [b c], Jean-Philippe Nougayrède [b], Isabelle P. Oswald [a]

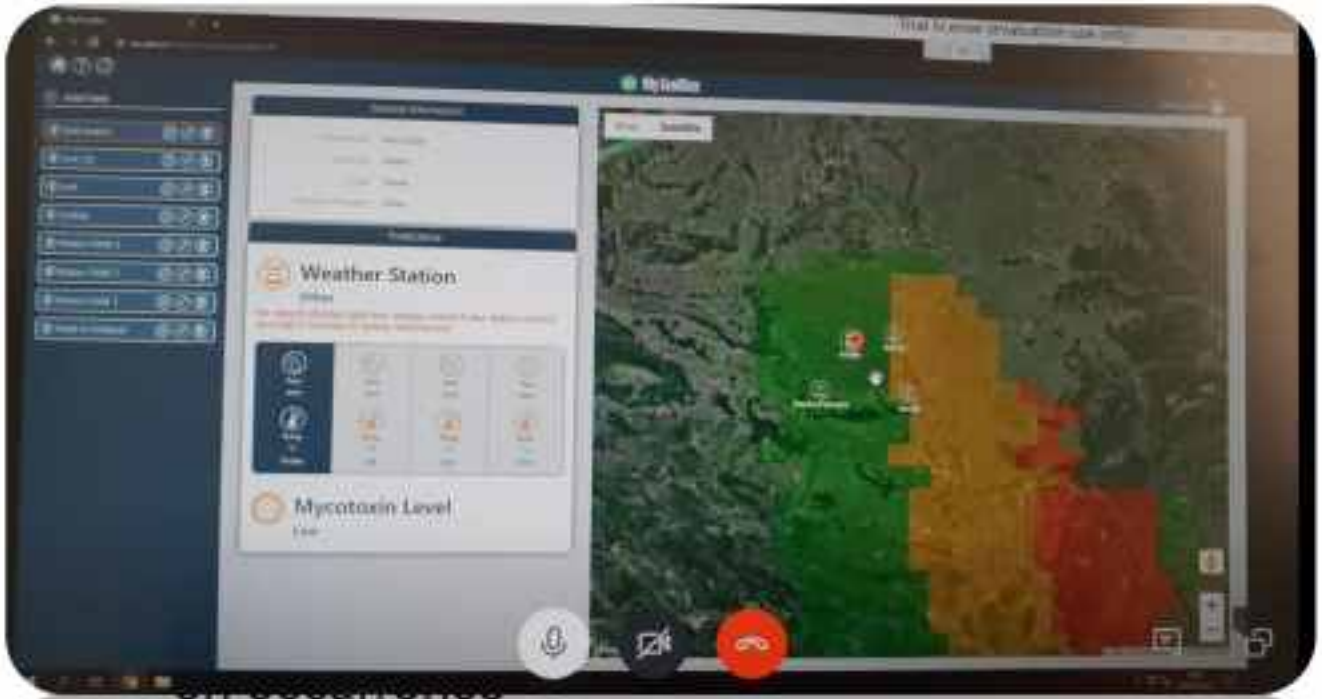


DON increases genotoxicity induced by colibactin, a bacterial toxin produced by certain strains of *E. coli* bacteria in the large intestine

Emerging risk definition to be extended:

Known hazard + New evidence for combined toxicity

Stressor climate change: Monitoring the occurrence of (emerging) secondary metabolites in food crops (Case)



- leads to **accurate forecasting**

Food Control 180 (2026) 112258

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Mycotoxin field trial uncovers first aflatoxin B1 occurrence in maize in Lower Austria

Patrick Rennhofer [a], Michael Sulyok [a], Dedy Leonardo Nadeak [a], Hermann Buerstmayr [b], Rudolf Krska [a,c], Stephan Freitag [a,*]

[a] BOKU University, Institute of Bioanalytics and Agro-Metabolomics, Department of Agricultural Sciences, Konrad Lorenz Str. 20, Tulln, 3430, Austria
[b] BOKU University, Institute of Crop Breeding and Genetics, Department of Agricultural Sciences, Konrad Lorenz Str. 20, Tulln, 3430, Austria
[c] Institute for Global Food Security, School of Biological Sciences, Queens University Belfast, University Road, Belfast, Northern Ireland, BT7 1NN, United Kingdom

LANDWIRTSCHAFT

Aflatoxin: „Mais wird ständig kontrolliert“

Für Aufregung sorgte die Entdeckung eines Forscherteams der Universität für Bodenkultur, das im Mais auf einem Versuchsfeld in Tulln das Gift Aflatoxin nachwies. Von der Landwirtschaftskammer heißt es, es werde seit Jahren ständig kontrolliert.

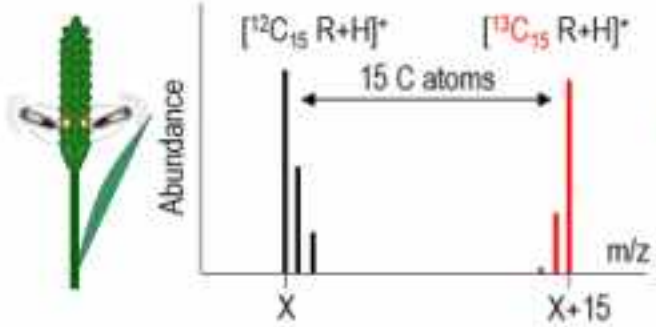
WISSENSCHAFT

Giftiger Schimmelpilz in Mais entdeckt

Forscher an der Universität für Bodenkultur in Tulln entdeckten einen Schimmelpilz, der zu

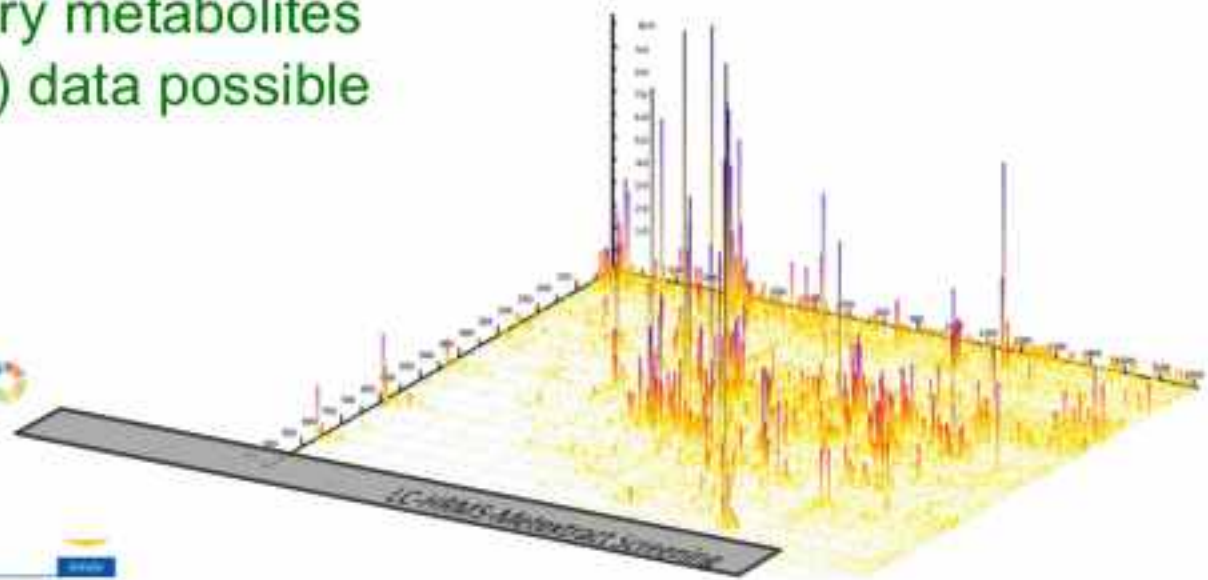
How to identify emerging hazards

against the backdrop of climate change and plant breeding?



LC-High Resolution Mass Spectrometry

- full scan of all/new secondary metabolites
- reinterrogation of (historical) data possible



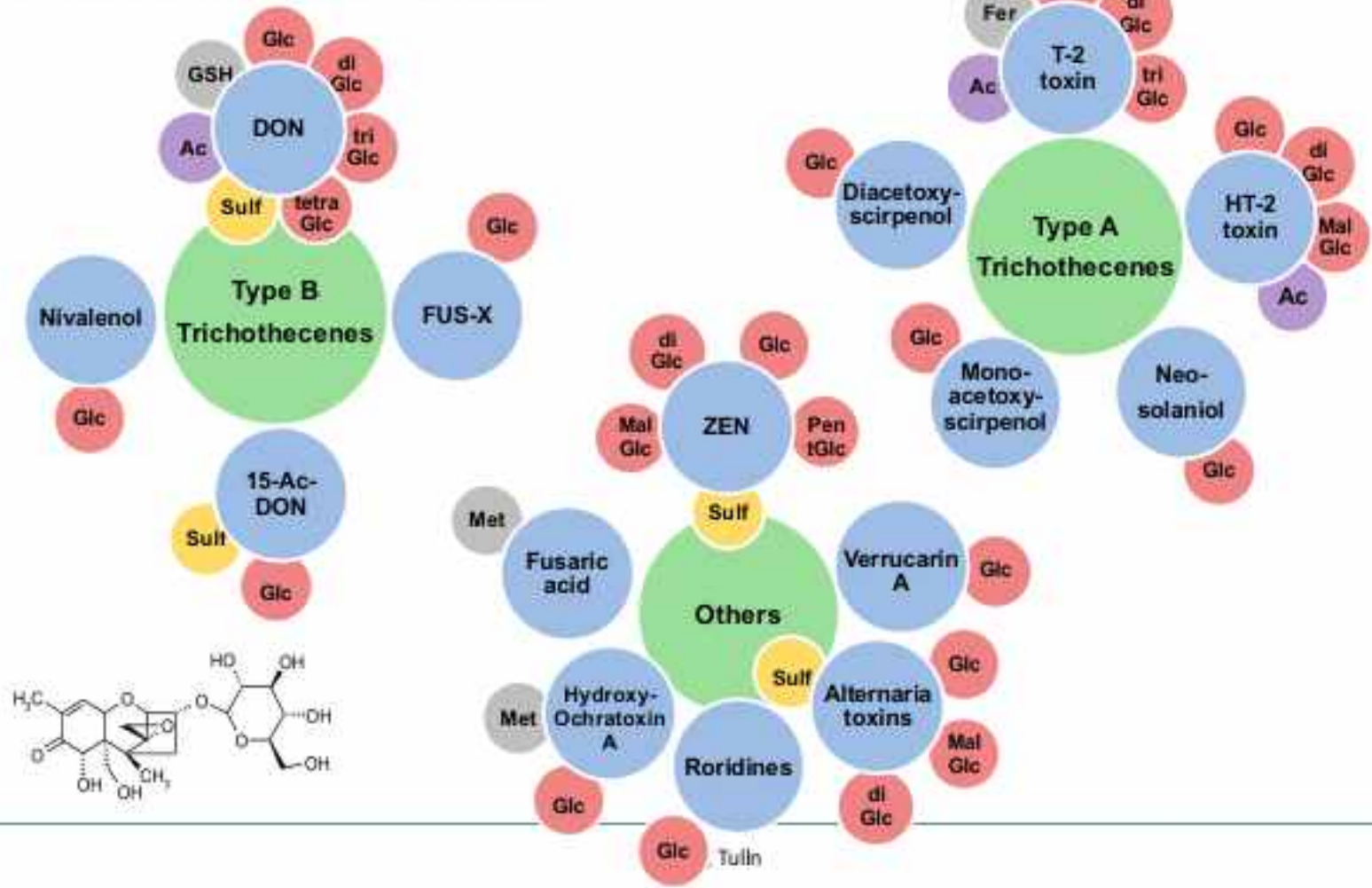
analytical chemistry

DOI: 10.1021/acs.analchem.7b02518
Anal. Chem. 2017, 89, 9518−9526

MetExtract II: A Software Suite for Stable Isotope-Assisted Untargeted Metabolomics

Christoph Bueschl,[†,⊥] Bernhard Kluger,[†] Nora K. N. Neumann,[†] Maria Doppler,[†] Valentina Maschietto,[†] Gerhard G. Thallinger,[‡,∥] Jacqueline Meng-Reiterer,[†,#] Rudolf Krska,[†] and Rainer Schuhmacher*[,†,⊥]

What can only be seen by LC-MS based multi-toxin approaches?



Furan in Foods

Furan is widely present in foods because it can be formed from multiple precursors through different heat-induced pathways.

Carbohydrates | Amino acids | Polyunsaturated fatty acids | Carotenoids

Heat-Induced Pathways

Maillard reactions Thermal degradation
Oxidative processes

- Food composition, Processing time and temperature, Oxidation conditions
- pH, Irradiation
- Presence of metals

IARC classified furan as **"possibly carcinogenic to humans" (Group 2B)**

Pilot plant / industrial scale DoE on different food sauces production

Bolognese Sauce Market Samples

	furan	furans sum
average:	52	97
max:	71	131

State-of-the-art:
HS-SPME-GC–MS/MS method with stable isotope dilution analysis

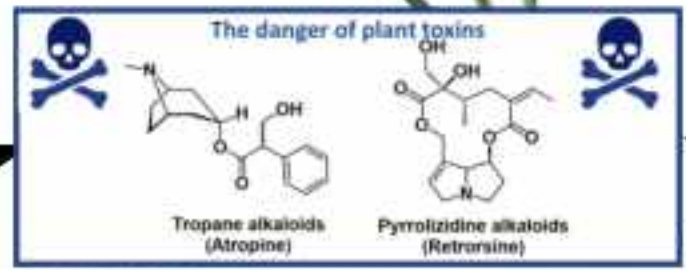
Plant-based products

Cereal harvesting

Datura stramonium

Senecio angustifolius

Rooibos harvesting



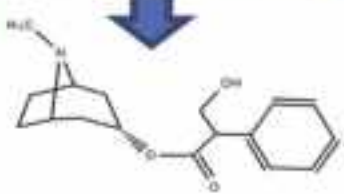
Pasta

Herbal tea

Stressor Climate Change & plant toxins: 200 tropane alkaloids: decreased heartrate, hallucinations,…

Datura in soybean and maize

Especially a problem in organic farming

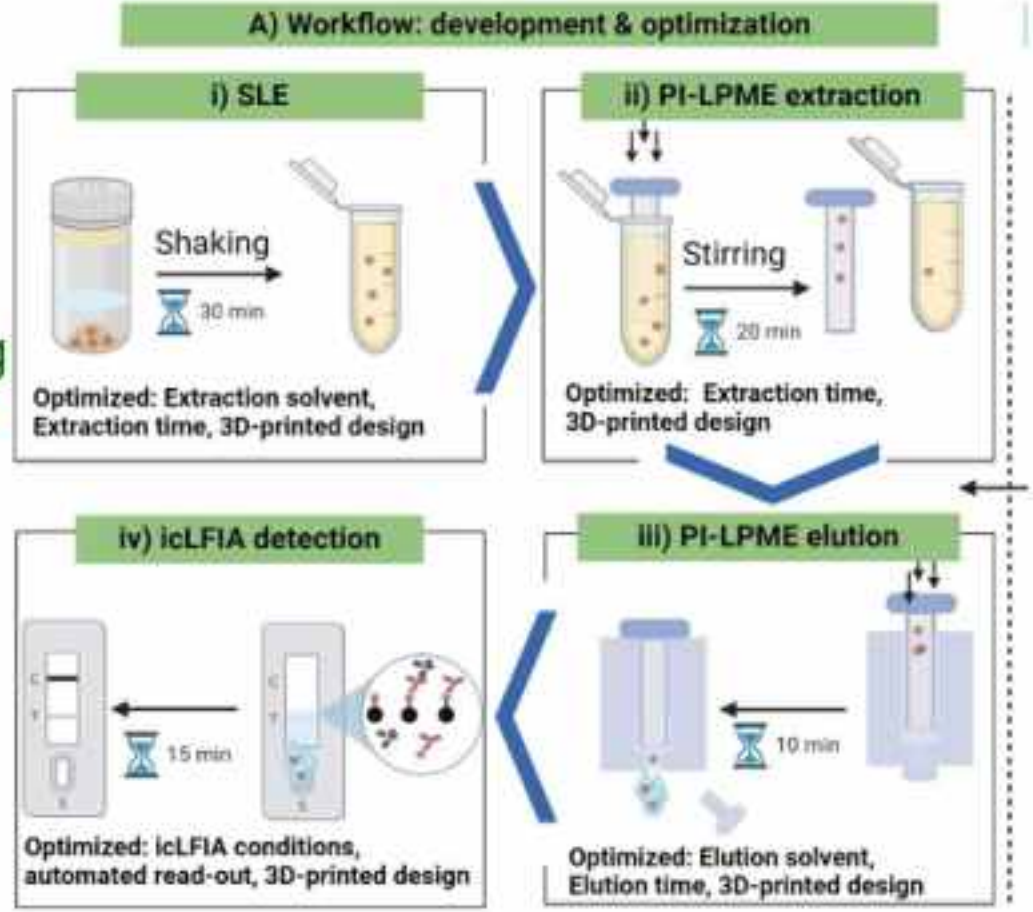


- most frequent toxin: **atropine (EU limit for grain-based baby food)** & **scopolamine**
- **Recall of Tortilla chips**

Gerhard Adam, R. Krska, 2023

Rapid detection of tropane alkaloids (TAs)

- **Sample preparation** using **paper immobilized liquid-phase micro-extraction**
- Pre-validated for **buckwheat cereal samples** at 5 to 10 µg/kg contamination levels of atropine



analytical chemistry

Article

Modular Point-of-Need Tropane Alkaloid Detection at Regulatory Levels: Combining Solid–Liquid Extraction from Buckwheat with a Paper-Immobilized Liquid-Phase Microextraction and Immuno-Detection in Interconnectable 3D-Printed Devices

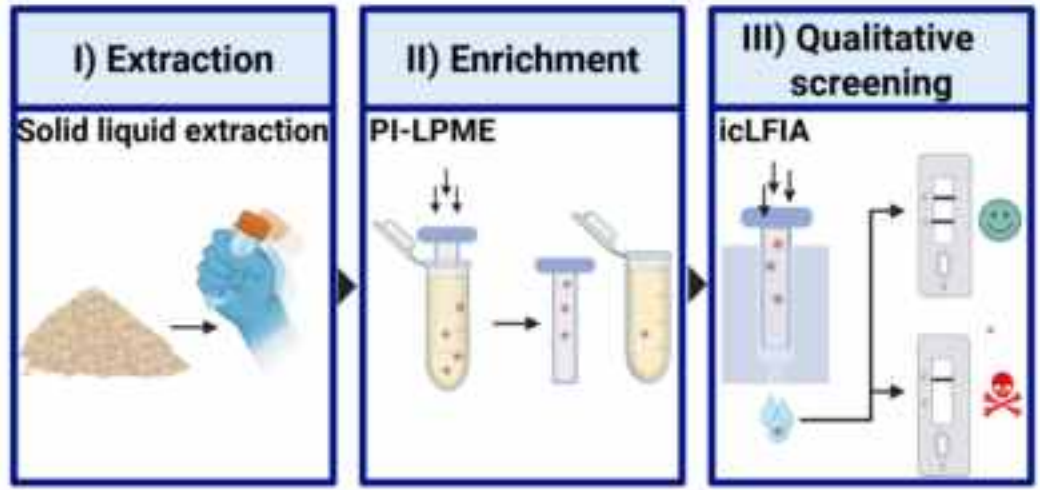
Ids B. Lemmink, Linda Willemsen, Erik Beij, Toine F. H. Bovee, Han Zuilhof, and Gert IJ. Salentijn*

Validation of the novel test kit for tropane alkaloids

Development & validation of a rapid test for tropane alkaloids

Lemmink et al, Point-of-Need Tropane Alkaloid Detection. Analytical Chemistry
Lemmink et al, Paper-immobilized liquid phase microextraction. Analytica Chimica

Workflow of the 3D-printed biosensing toolkit

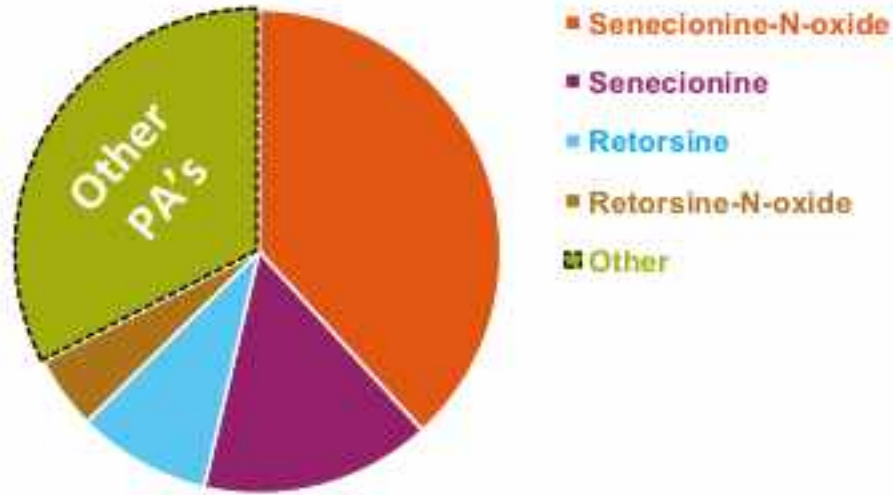


Pyrrolizidine alkaloids in Rooibos

Co-harvesting of *Senecio Angustifolius*

Distribution of pyrrolizidine alkaloids (PAs) in Rooibos

Four substances account for 70% of PAs in Rooibos

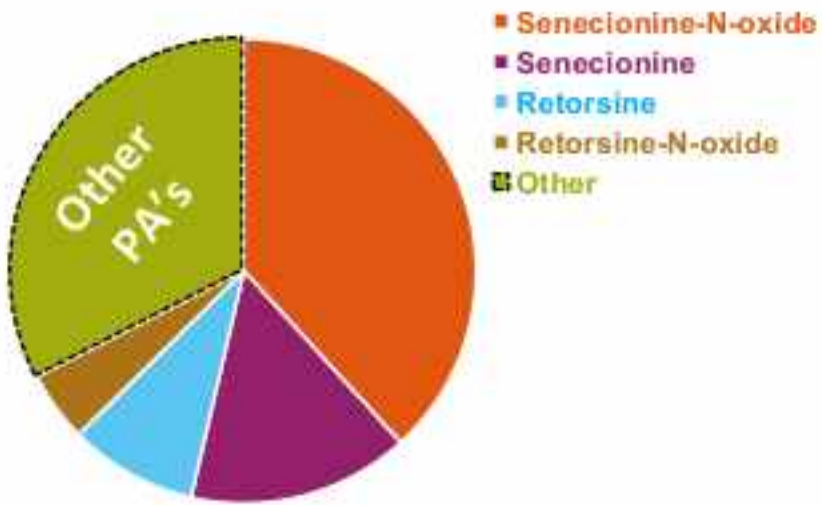


Picron et al, Analytical strategies for pyrrolizidine alkaloids in plant based food. 2018, Food Chemistry

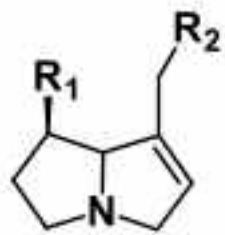
Towards rapid pyrrolizidine alkaloid detection

Development and validation of a rapid test for pyrrolizidine alkaloids

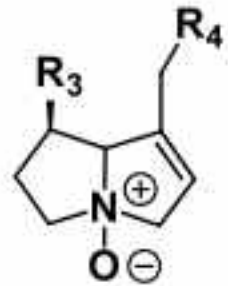
Distribution of pyrrolizidine alkaloids in rooibos



Pyrrolizidine alkaloids



Pyrrolizidine alkaloid



Pyrrolizidine alkaloid N-oxide

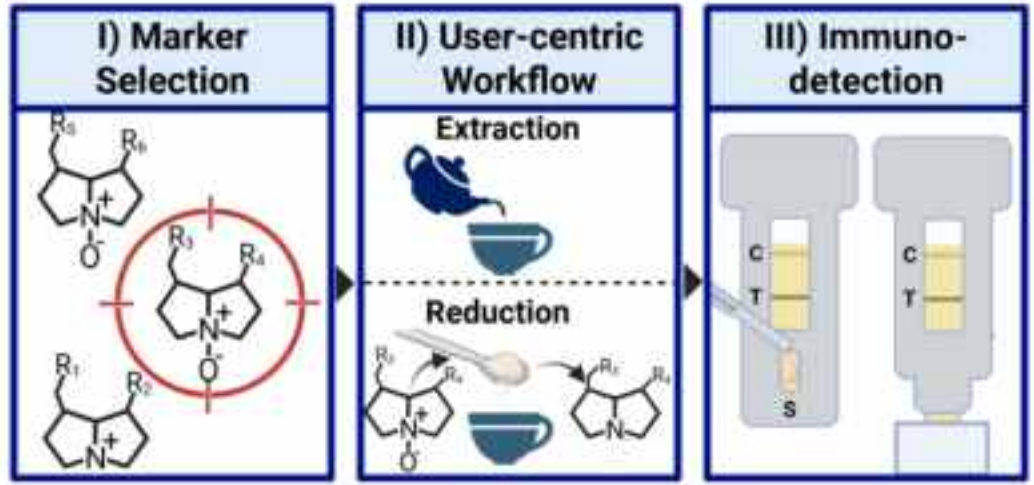
Legislated as the sum of **35** pyrrolizidine alkaloid-(N-oxides) at 400 µg kg^{-1} in rooibos

Towards rapid pyrrolizidine alkaloid detection

Development and validation of a rapid test for pyrrolizidine alkaloids

Lemmink et al. Point-of-need immunoassay for pyrrolizidine alkaloid. *In preparation*

Workflow of the 3D-printed biosensing toolkit



Validation exercise

Test the pyrrolizidine alkaloid test kit in ≥6 EU-member states

FFoQSI

GHENT UNIVERSITY

BfR
Bundesinstitut für Risikobewertung

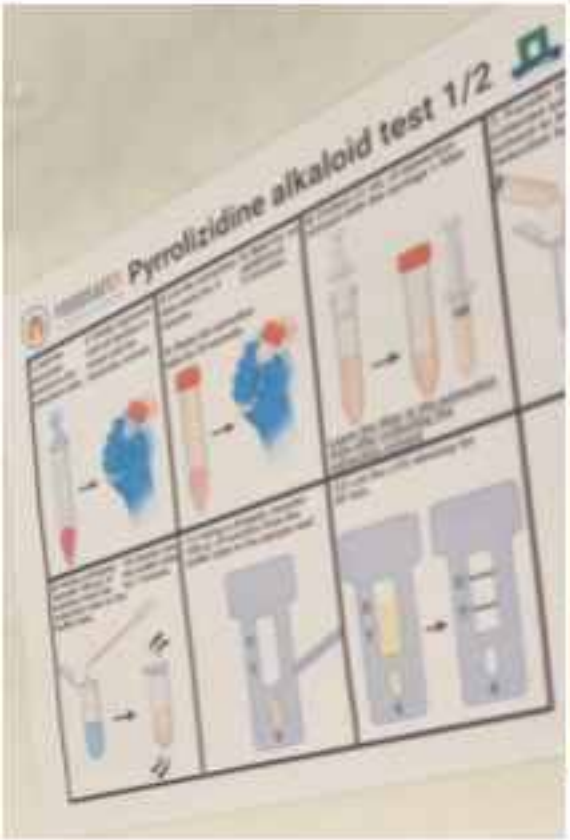
PIWet

QUEEN'S UNIVERSITY BELFAST

WAGENINGEN
UNIVERSITY & RESEARCH

Singapore Food Agency

International user-validation: production



FFoQSI and BOKU/IFA-Tulln – head office members **validating pyrolizidine test kits** in the chemical lab (Case 4)

Drivers of (emerging) food safety hazards/risks

Social Drivers

Consumer behaviour:
- gluten free, high fibre, ...

Technological Drivers

Technologies in food production:
- Novel food sources (insects)
- Thermal degradation of toxins

Economic Driver

Distribution:
- Food fraud, Authenticity
- Proper Storage

Environmental Drivers

Environmental contamination:
- Pesticides, heavy metals
- Bioaccumulation of toxins

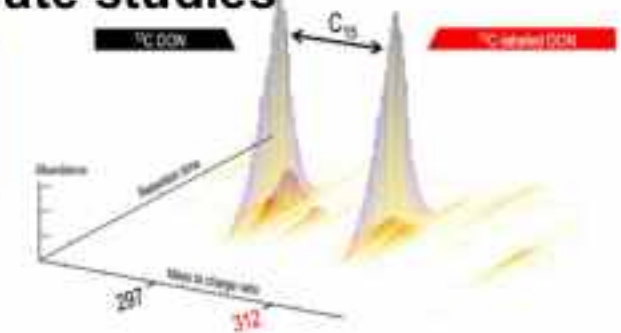
Political Drivers

Legislation, policies and governance:
- Food safety monitoring (RASFF)

Gluten-free pasta: thermal degradation of mycotoxins

Aflatoxins, Fumonisins & T2/HT2 Toxins are ??? degraded during commercial pasta making in an industrial environment

- ial **degradation** of
- during **thermal**
- **essing** under semi- industrial conditions
- in **gluten free** (=maize) pasta
- Using LC-HRMS based C12/C13 **tracer fate studies**



Conclusions and future needs

- For each of the **5 major drivers of (emerging) food safety hazards** **analytical chemistry** is crucial to manage the challenges:
  - **LC-MS/MS** for the **ultra-fast quantification** of multiple classes of chemical substances. Provides **selectivity**, **sensitivity** and **speed** even in complex food and feed
  - **SIL assisted LC-HRMS** approaches reveal **novel conjugated metabolites**, also ideal for **long term monitoring** against the backdrop of climate change
  - **Stable isotope assisted LC-MS based tracer fate studies** provide novel insights into the **fate of mycotoxins during thermal processing**
- **Indirect competitive lateral flow immunoassay for atropine** has been developed
- Novel approach for the **determination of pyrrolizidine alkaloids** in **Rooibos** based on a **3D-printed biosensing toolkit** introduced
- **Portable spectroscopy** devices e.g. XRF (combined with ML) as a new tool to **determine illegal lead chromate in turmeric** developed and tested

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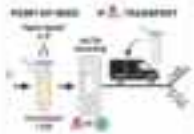
my.foodsafer.com/site/training

Targeted Stakeholder Group | Topic | Content Format



Paper-immobilized liquid-phase microextraction for direct paper...
Atropine is a strictly regulated natural toxin. Monitoring for atropine is thus important, but often expensive and time-consuming. Moreover, the range of relevant matrices, and corresponding differences in required detection limits for atropine vary. Therefore, we developed a more simplified and affordable method, combining immunodetection and...

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A FoodSafeR perspective on emerging food safety hazards and...
Scientific Publication. Both new and old microbial and chemical hazards were identified for inclusion in a central database. The database could be used to develop artificial intelligence (AI) models to explain existing and predict emerging food safety risks. The goal of this paper is to alert the global food safety community of the availability of this...

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Review report on available models for fungal infection and...
An overview of the currently available prediction models for fungal infection and mycotoxin production in grains and tomatoes.

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Introduction to predictive modelling for early warning mycotoxins

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THANK YOU!

FOODSAFER IS MAKING FOOD SAFETY EVERYBODY'S BUSINESS

Curated by the scientific community, FoodSafeR aims to be a trusted source of information, guidelines and advice in relation to emerging hazards that are posing a risk for food safety.

https://foodsafer.com

https://worldmycotoxinforum.org

On behalf of the general conference chairs, Prof. Rudi Krska and Prof. Chris Elliott, **WMF2027** warmly invites researchers from universities, research institutes, and industry to submit abstracts for ORAL and/or POSTER presentations.