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Environmental and Food Safety of Spices and Herbs along Global Food Chains

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HIGHLIGHTS

- An overview on food safety of dried spice and herb products is provided.
- A description of EU FP7 project SPICED is provided.
- Scientific reports on food safety of spices within project SPICED are discussed by topic.

ABSTRACT

Spices and herbs, which are consumed in small quantities, but used in a wide range of foods and food products, represent a unique segment within the food sector. Moreover, being distributed as mostly in their dried, low water activity formats and associated with very complex distribution product chains, specific concerns as regards food safety apply to these particular commodities. To promote the capability of the food sector and the society to detect, respond to and prevent bio-threats, data generated from the EU FP7 project "Securing the spices and herbs commodity chains in Europe against deliberate, accidental or natural biological and chemical contamination" (SPICED) are presented thematically including: general considerations and issues of sampling, chemical and microbial contamination, and to food chain and societal aspects.

Keywords: Herbs and spices; Accidental or deliberate contamination; Pesticide residues; Mycotoxins; Pathogenic microorganisms; Trade network; Vulnerable points

1. Introduction

Herbs and spices have long been associated with the human culture, and these condiments have been used to flavour our foods since ancient times. Moreover, as they represent highly valued ingredients, spices have affected human activities such as exploration and trade, and thus, indirectly impacted on human history. Currently, spices and herbs are highly commercialised, similarly to the vast majority of marketed goods, within globalised systems, where the source of cultivation and harvesting may be quite distant from the points of consumption, and spice products may reach the consumers through a series of long and complex food commodity chains. Moreover, timeline from harvest of raw material till consumption can be years which often results in hardly transparent product pathways of spices. Consequently food safety of herbs and spices became an issue of high priority to protect the health of the consumers.

The European Union (EU) is one of the world's largest markets for herbs and spices, most of which are imported as dried raw materials from regions outside the EU. Despite the low water

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activity, which inhibits microbiological growth, spices and dried herbs and spices are natural products which can be contaminated with a variety of microorganisms among them pathogenic and toxigenic species. Moreover, chemical contaminations may also occur and mainly result from natural or unintentional inclusions, but may also arise from deliberate origin of food adultery or other malevolent causes.

2. Benefits and risks from spices

Although herbs and spices are used and consumed only in small quantities, they are added to a great variety of foods, especially to ready to eat (RTE) foods, and therefore, assessment of their intake has become an important topic. The physiological effects (Hirasa & Takemasa, 1998), health benefits (Tapsell et al., 2006; Williams, 2006; Peter, 2012b) e.g. antioxidant properties (Risch & Ho, 1996; Craig, 1999; Lampe, 2003; Low Dog, 2006; Charles, 2013), anti-inflammatory properties, and medicinal uses of spices (Duke, 2002; Peter, 2012b) e.g. in cancer therapies (Ho et al., 1994; Kaefer & Milner, 2008; Ferrucci et al., 2010) have long been recognised. In fact, recent large scale cohort studies (Lv et al., 2015; Chopan & Littenberg, 2017) have found a negative correlation between total mortality as well as leading causes of death (cancer, ischemic heart diseases and respiratory diseases) in the population studied and their regular consumption of spicy foods.
Nonetheless, spices have also been associated with certain illnesses or dysfunction syndromes, particularly of the digestive tract (Esmaillzadeh et al., 2013), and have been associated with food-borne infections (Zweifel & Stephan, 2012). This clearly is a human health risk factor by itself, yet the major health risks have been mostly associated not with the natural components in spices, but with various contaminants occasionally occurring in spice products from technological or other sources. Contaminations with microbiological and chemical agents can take place at numerous vulnerable points within production and supply chains and can pose a serious risk for the consumer. As quantitatively minor food ingredients, spices and herbs hold a major potential to contaminate a wide range of products due to the wide-spread use and large-scale distribution. However, the identification of contaminated spices and herbs as a cause of a foodborne infection or intoxication would be difficult, because outbreak investigations often focus on the major food ingredients and, in general, the cause of infection in food-borne outbreaks is proven in less than 20% of all cases (EFSA, 2016). Moreover, many common detection methods are less than suitable for heterogeneous herb/spice matrices.
Contamination potentially occurring at various points along the production and supply chain may pose a health risk to consumers. To comply with its legal mandate to assess the safety through scientific evidence based evaluation of all food products authorised in EU markets (EC, 2002), the European Food Safety Authority (EFSA) provides independent scientific advice to the European Commission and EU Member States to set maximum residue levels (MRLs) for organic micro-contaminants in spices as food commodities (EC, 2005), and issues scientific opinions on the public health risk posed by pathogens that may contaminate food of non-animal origin, including herbs and spices (along with fruits, vegetables, juices, seeds, nuts, cereals, mushrooms, algae, etc.) (EFSA, 2013).

3. Project ‘SPICED’

In a series of EU-supported research attempts to detect, respond to and prevent bio-threats, a project entitled “Securing the spices and herbs commodity chains in Europe against deliberate, accidental or natural biological and chemical contamination” (SPICED) within the EU FP7 Programme was initiated in 2013 in order to further increase the safety of the supply chains in Europe (SPICED, 2017). The overall objective of the EU project SPICED was aimed at securing the spice and herb food chains from primary production through to consumer-ready food against major natural, accidental or deliberate contaminations. Within SPICED, the focus was on low-moisture food ingredients such as dried herbs and spices. The research objectives of the SPICED project focused on i) characterising the heterogeneous matrices of spices and herbs based on their respective production and supply chains concerning relevant biological and chemical hazards that can lead to major natural, accidental or deliberate contaminations in the food chain. Furthermore, the focus was on ii) improving knowledge regarding biological hazard properties as well as developing on-site and high throughput diagnostic methods for appropriate agent detection and iii) reducing (industrial) chemical adulterations along with ensuring the authenticity of spices and herbs by evaluation and improvement of non-targeted fingerprinting methods. Additionally, the project focused on iv) improving alerting, reporting and decontamination systems as well as techniques to ensure a high level of prevention and response.

Tasks in project SPICED proceeded in an inter-related manner towards matrix chain modelling, chemicals hazards and biological hazards, as depicted in Figure 1. Among other tasks the production and supply chains of herbs and spices were analysed in order to identify possible vulnerable points for the entry of contaminants and to acquire new findings on consumer behaviour. To achieve this objective, heterogeneous matrices of spices and herbs and their respective intra- and interplant production and supply chains were characterised in context with relevant chemical and biological hazards that can potentially lead to major deliberate, accidental or natural contamination in the food supply chain, as seen in Figure 2.

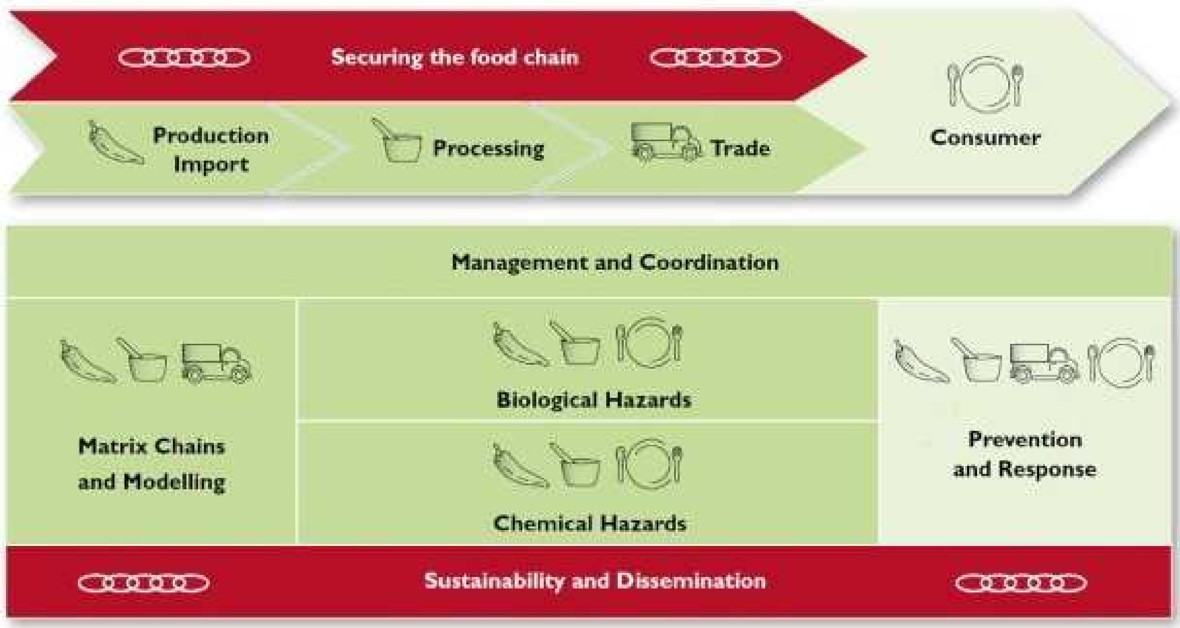

Figure 1. The structure of project SPICED spanning from production and import to the consumer.

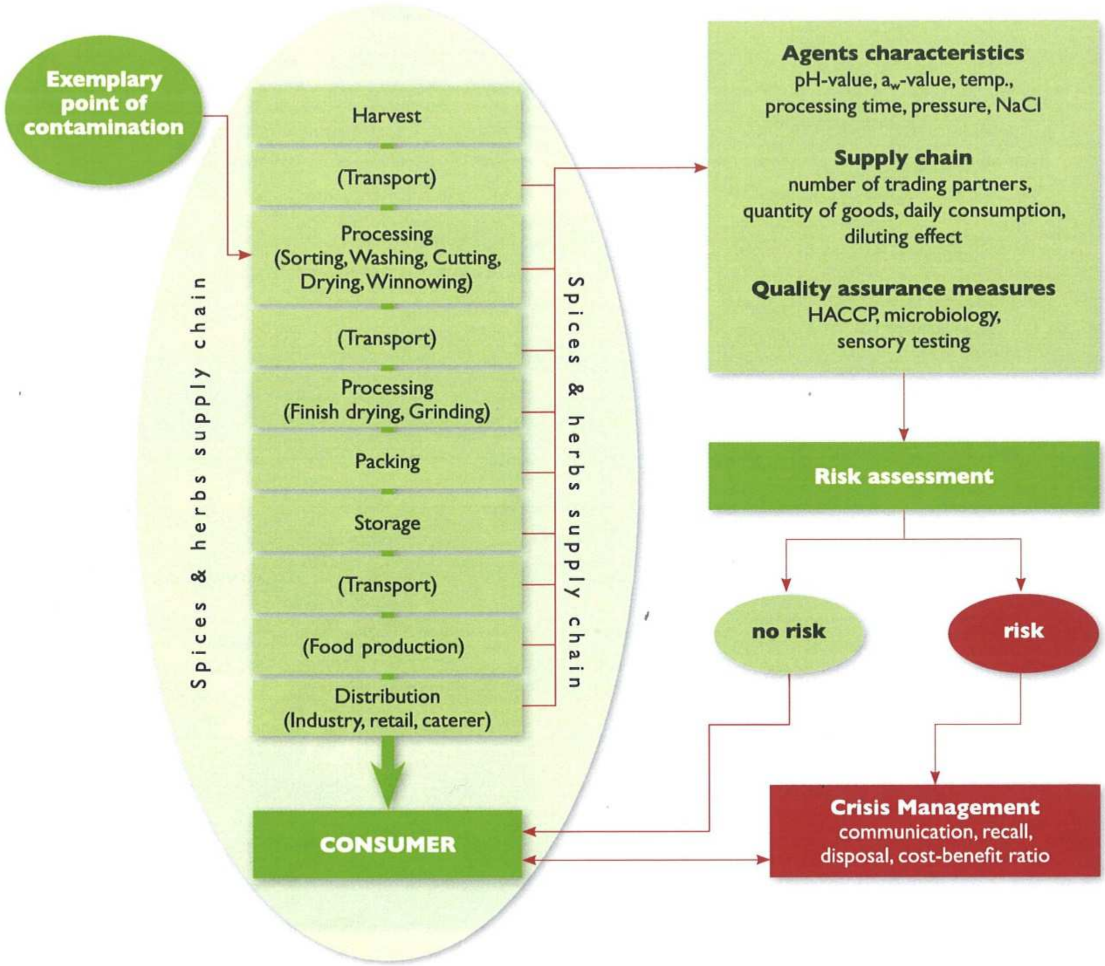

Figure 2. Spices and herbs supply chain with a hypothetical exemplary point of contamination (e.g. accidental, intentional) and the corresponding hazard identification and risk assessment steps.

The project was co-ordinated by the German Federal Institute for Risk Assessment (BfR, Germany), participant research organisations included the Agro-Environmental Research Institute (AERI) and Food Science Research Institute (FSRI) of the National Agricultural Research and Innovation Centre (NARIC, Hungary), the Austrian Agency for Health and Food Safety (AGES, Austria), the Bundeswehr Research Institute for Protective Technologies and NBC-Protection (WIS, Germany), the Food Science Research Centre, University of Limerick (UL, Ireland), FUCHS Gewürze GmbH (Germany), the Institute of Food Safety (DLO/RIKILT, the Netherlands), the Institute of Food Safety, Animal Health and Environment (BIOR, Latvia); the Laboratory of Food Microbiology, Wageningen University (WU, the Netherlands) and the National Agricultural and Food Centre (VUP, Slovakia), with management support provided by RTD Services (Austria). Results achieved in Project SPICED are presented in this Special Issue by its Guest Editors (ASz and MGW) and by the initiating Co-ordinator of Project SPICED (BA). Articles have been organised in a thematic order from general considerations to chemical and microbiological contamination as well as to trade and societal issues, discussed below.

4. General considerations, sampling

Risk assessment of contaminants in spices has to consider both the hazard these contaminants may represent to human (or environmental) health and the expected exposure to these substances. A risk matrix compiled from the severity of the adverse effects on the basis of available toxicological reference levels and the probability of exposure on the basis of historical data from available monitoring surveys and the frequency of notifications in the Rapid Alert System for Food and Feed (RASFF) of the EU (RASFF, 2017) allows risk ranking of chemical contaminants in spices, as reported in this issue by Esther D. van Asselt et al. Traceability is an important concept in maintaining food safety, however, it can be a major challenge in the global trade chains of dried culinary herbs and spices due to the very complex production and trade chains of spices and food products which contain them. Proper and standardised documentation, as well as harmonised information technology tools are of essential importance in the sector as pointed out by Schaarschmidt et al. A key to effective identification of contamination is the choice of proper sampling strategies, discussed by Bouzembrak & van der Fels-Klerx. Sampling is known to be the step in the analytical process of the highest experimental random error, and sampling plans based on stratified random sampling may provide improved efficacy at higher expected contaminated levels, and spice contamination monitoring can be facilitated by network analysis, e.g. with Bayesian networks as discussed by Bouzembrak et al.

5. Chemical contamination

The vast majority of organic micro-contaminants in spices originate from three main sources: mycotoxins from phytopathogenic fungi, pesticide residues and substances used in food adulteration. Mycotoxins are mostly originated from harvesting and subsequent storage, and are of major concern, because these secondary metabolic substances may exert advert effects, e.g. carcinogenicity or endocrine disruptive effects on humans or other organisms exposed. Although various decontamination methods exist against mycotoxinogenic fungi (see ‘Microbial contamination’, below), those methods are effective only if applied before mycotoxin contamination has occurred. Pesticide residues mostly originate from agrochemical treatments of the cultivated spice plants to protect them against various weeds, fungi or pest animals (mostly insects). As regards to these contaminants, compliance with technology specifications in cultivation, harvest and storage is of essential importance to avoid mycotoxin and pesticide contamination (Chakraverty et al., 2003; Bosland & Votava, 2012), and the rational use of pesticides is necessary to avoid MRL violations (Peter, 2006, Klátyik et al., 2014, 2016). In addition to these two categories of main chemical contaminants, occasionally technological contamination may occur with unintended substances, e.g. polycyclic aromatic hydrocarbons (PAHs), anizoles, benzidines, unsubstituted, halogenated biphenyls or other compounds. Unlike the above chemical contaminants appearing in spices mostly as accidental contamination, other substances may occur as deliberate contamination due to financial reasons (spice adulteration) or other malignant intentions.
As seen, the “from farm to fork” concept strongly anchors environmental safety in the assessment of food safety, integrating Environmental Risk Assessment (ERA) as an essential part of safety evaluation. Moreover, as pointed out recently, adverse effects of pesticides are attributed not only to pesticide active ingredients and their metabolites, but also to various additives, agricultural surfactants used e.g. in the formulation of plant protection products (Klátyik et al., 2014), therefore, the possible presence of these co-formulants, previously considered ‘inert’ is also expected to have to be monitored in the future. Research on surfactants emerging as contaminants associated with pesticide residues studied in project SPICED has been co-sponsored at the Hungarian consortium partner by the Hungarian

Scientific Research Fund (OTKA). Routine monitoring of chemical contaminants is expected to increasingly rely on biosensorics (Bhunia et al., 2015; Adányi et al. 2017), also applicable for detecting microbial contamination.
In this Special Issue, chemical contamination is covered by Rozentale et al. reporting the occurrence of polycyclic aromatic hydrocarbons in oregano, basil, black pepper and paprika, and by Molnár et al. assessing chemical contamination patterns as an indicator of origin of spice paprika.

6. Microbial contamination

Microbial food safety is probably the safety aspect of the greatest concern in the case of dried spices and herbs (McKee, 1995; Sagoo et al., 2009; Vitullo et al., 2011; Gurtler et al., 2014). Due to their low water activity, microbial contamination may persist in these products, and thus, spices and herbs can be sources of outbreaks of foodborne diseases (Zweifel & Stephan, 2012). To assess and mitigate this risk due to microbial hazards, risk profiles were developed for spices e.g. by the US Food and Drug Administration (US FDA, 2013) or EFSA (EFSA, 2013). Decontamination technologies as possible means to eliminate or mitigate microbial contamination in spices are widely accepted (Chakraverty et al., 2003; Peter, 2006), and the importance of proper quality specifications and indices has been emphasized (Hirasa & Takemasa, 1998; Peter, 2012a; Kónya et al., 2014).
Although dried spices and herbs can be sources or media for microbial contamination, certain representatives have been associated with their own inherent antimicrobial activity. These antimicrobial effects of spices have been widely reported (Hirasa & Takemasa, 1998; Tajkarimi et al., 2010), and certain spices and their mixes (e.g. clove, cinnamon, oregano, rosemary) have been suggested as potential alternative options for replacement of conventional food preservation additives due to their antibacterial effects (Deans & Ritchie, 1987; Mytle et al., 2006; Pina-Pérez, Martínez-López & Rodrigi, 2012; Moore-Neibel et al., 2013; Fernández-López et al., 2005; Matan et al., 2006, Fei et al., 2011).
In accordance with the importance of the topic, the majority of the articles in this Special Issue focus on microbial safety of spices. Occurrence and tenacity of *Salmonella* spp., *Bacillus cereus* and *Staphylococcus aureus* in dried spices and herbs are reported in three studies (Lins; Baiba et al., Thanh et al., respectively), and *B. cereus* species were characterised by their phylogenetic and toxicogenic characteristics by Frentzel et al. Molecular biological methods for the detection and quantification of microorganisms from spices were described in two reports (Minarovičová et al.; Frentzel et al.), and were applied for possible determining the geographical origin of spice paprika samples (Bata-Vidács et al.) and for high-throughput detection of pathogenic bacteria in spices and herbs (Planý et al.). Of nine condiments tested, oregano and cinnamon were found to exert strong microbial activity against a *Salmonella* strain (Lins), and decontamination methods, e.g. irradiation and steaming, microwave heating alone and combined with re-wetting, as well as radio-frequency heat treatment were compared both for efficacy and for their effects on spice paprika composition (Molnár et al).

7. Trade and societal issues

Both cultivation and trade in spices and herbs have been substantially growing during the last decades (FAOSTAT, 2016). The leading spice commodity worldwide, both by volume and value, is black pepper, followed by spice paprika (*Capsicum* species) (Parthasarathy et al., 2008; Bosland & Votava, 2012). Due to the highly complex food product chains, assurance of food safety has to use different approaches when assessing large manufacturers with strict in-

house quality control and also smaller suppliers from less controlled supply chains. This underlines both the importance of quality control measures in spice processing (Peter, 2012a; Kónya et al., 2016) on the one hand, and the possibility of leakage of contaminated spice commodities from domestic to export supply chains by circumventing control measures on longer supply chains (Daly, 2015) on the other hand.
In this Special Issue, trade and societal pertinences are discussed in two reports. In the approach presented by Lakner et al., proliferation of contaminated spice products within the European spice trade network is modelled by stochastic simulation for black pepper and spice paprika. Trade flows analysed in a multi-step assessment revealed characteristic geospatial distribution shown to be related to economic factors of the modelled supplier and receiver countries, allowing policy implications also to be discussed. Another report by Szűcs et al. evaluated spice consumption habits in seven EU member states. The questionnaire survey identified pepper, paprika, parsley and basil as being the most frequently consumed spices and herbs in these countries, and showed, amongst others, that consumption of typical national spices and nation-specific characteristics in the consumption habits are still apparent, despite on-going globalisation trends noted in spice consumption.

8. Conclusions

Results achieved in Project SPICED are presented in this Special Issue by its Guest Editors (ASz and MGW) and by the initiating Co-ordinator of project SPICED (BA). Articles have been organised in a thematic order from general considerations and issues of sampling to chemical and microbial contamination, and to trade and societal aspects. Although the results of Project SPICED are broader and further-reaching than those presented in this Special Issue, these reports represent both important and timely contributions towards environmental and food safety aspects of spice and herb commodities, by supporting effective protection of the consumers from possible risks due to accidental or deliberate contamination of spices and herbs.

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