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E.F. Hoek-van den Hil, E.D. van Asselt

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This research has been carried out by Wageningen Food Safety Research, institute within the legal entity Wageningen Research Foundation funded by the Dutch Food and Consumer Product Safety Authority (NVWA) (project number BO-43-001.01-004).

Wageningen, June 2019

WFSR report 2019.006

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Hoek-van den Hil, E.F., E.D. van Asselt, 2019. *Chemical hazards in the mushroom supply chain.* Wageningen, Wageningen Food Safety Research, WFSR report 2019.006. 64 pp.; 1 fig.; 5 tab.; 164 ref.

Project number: 1287370301
BAS-code: BO-43-001.001-004
Project title: Gevaarevaluatie Voedselgewassen
Project leader: E.D. van Asselt

This report can be downloaded for free at https://doi.org/10.18174/476347 or at www.wur.eu/food-safety-research (under WFSR publications).

P.O. Box 230, 6700 AA Wageningen, The Netherlands, T +31 (0)317 48 02 56, E info.wfsr@wur.nl, www.wur.eu/food-safety-research. WFSR is part of Wageningen University & Research.

WFSR report 2019.006

Distribution list:
- Marca Schrap, NVWA
- Jacqueline Castenmiller, NVWA
- Linda Kox, NVWA
- Jos Cornelese, NVWA

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Summary

This report describes the chemical hazards that may occur in the mushroom supply chain both for wild and for cultivated mushrooms. These results will be used by the department for Risk Assessment & Research (BuRO) of the Netherlands Food and Consumer Product Safety Authority (NVWA) as input for their chain analysis of the mushroom supply chain. This assessment will be used as input in the NVWA monitoring plans to achieve a risk-based monitoring program.

Long list of chemical hazards that might occur in the mushroom supply chain
A literature study was performed to identify possible chemical hazards in the mushroom supply chain from farm-to-fork. Apart from the literature review, Dutch monitoring data were obtained from the KAP database (2013-2017) and RASFF notifications (2013-2018) were downloaded from the RASFF portal. Based on the literature review and monitoring data, a long list that includes all chemical hazards that might occur in mushrooms was compiled. The long list consists of the following chemical hazards that can occur in cultivated mushrooms via the compost, which consists of plaster, horse and chicken manure and straw: heavy metals and other elements, pesticides, and possible veterinary medicinal product residues. During cultivation, residues of pesticides, cleaning and disinfection agents and perchlorate can occur. Additionally, nicotine has been found in wild and cultivated mushrooms. In wild mushrooms, substances present in the environment may accumulate in mushrooms, such as heavy metals, other elements, radionuclides and persistent organic pollutants. Natural toxins (mainly amatoxins) can be present in specific types of toxic wild mushrooms, which can be picked by mistake. During processing of mushrooms, flavour enhancers and colourants, cleaning and disinfection agents and perchlorate could be used and processing contaminants could be formed. Furthermore, mycotoxins can be formed during transport or storage. Allergens could also be present in mushrooms.

Intermediate list of prioritised chemical hazards
Based on all obtained information, the long list of hazards in the mushroom supply chain was prioritised to come to an intermediate list of chemical hazards. This intermediate list contains substances that were frequently found in mushrooms and/or found above the legal limits as well as unauthorized substances. The intermediate list includes the heavy metals and elements: cadmium, lead, mercury, arsenic, PGEs and aluminium. A few studies showed elevated levels of heavy metals (1 mg As/kg, 6 mg Cd /kg, >1 mg Pb/kg, 0.25-0.37 mg Hg/kg), PGEs (Pt > 5 mg/kg) and aluminium (17-19 mg/kg) in cultivated mushroom species from China, Poland and Spain. *Agaricus* (white button mushrooms, chestnut mushrooms and portobellos), which are the main consumed mushrooms in the Netherlands, did not contain high levels of these substances. The levels of heavy metals and other elements can be clearly higher in wild mushrooms as local levels of heavy metals in the environment may be high. Consequently, the heavy metal concentrations in wild mushrooms may exceed health-based guidance values (HBGVs).

Regulated maximum limits for radionuclides were not exceeded in cultivated mushrooms. Dependent on the presence of radionuclides in the environment, wild mushrooms could accumulate high radionuclides levels exceeding regulated MLs. Occasionally, ^{137}Cs, ^{226}Ra, ^{210}Pb and ^{210}Po were found above the EU legal or equivalent limits in wild mushrooms. Therefore, these were included in the intermediate list for wild mushrooms.

In the Netherlands, only three pesticides are approved for use in mushroom cultivation (deltamethrin, prochloraz and metrafenon). However, MRL exceedances were found in cultivated mushrooms for: bifenthrin, carbofuran, carbendazim, chlorpyrifos, deltamethrin, fenpropathrin, fipronil, procymidone, tetramethrin, β-cyfluthrin, β-cypermethrin and λ-cyhalothrin, based on literature and monitoring data. MRL exceedances in wild mushrooms were found for permethrin, propoxur and tetramethrin. Therefore, these pesticides were included in the intermediate list. The pesticides are currently all included in the multi-methods used for monitoring of pesticides in the Netherlands and as such will be found if present in mushrooms.

Some specific mushroom species can contain natural toxins, mainly amatoxins, which can be lethal. Therefore, collection of wild mushrooms for consumption can be risky, because toxic mushrooms can be mistaken for edible species. In the literature and RASFF notifications, several incidences with consumption or presence of amatoxins in edible mushrooms were found. Therefore, amatoxins were included in the intermediate list for wild mushrooms.

In the past, nicotine levels above the MRL have been found in cultivated and wild mushrooms. The cause of the presence of nicotine is still unknown. Therefore, nicotines were also added to the intermediate list. Disinfection agents (like formaldehyde, trihalomethanes, haloacetic acids, and chlorate) are needed in cultivation and processing of mushrooms. However data is limited, therefore more data are needed on the possible presence of disinfection residues. As a result, disinfection agents were also added to the intermediate list.

All substances in the intermediate list should be evaluated further to determine their possible risk for human health by combining concentrations found in mushrooms and consumption data. Substances with a possible health risk or substances with knowledge gaps should be included in the short list: the list that should be used to establish a risk based monitoring program for mushrooms.

Trends in the mushroom supply chain
Literature review and expert elicitation were used to identify upcoming trends that could influence the presence of chemical hazards in the mushroom supply chain. This revealed that mushrooms perfectly fit in the current consumer trends of health, sustainability, convenience and plant-based diets. Consumer trends, like increased use and consumption of mushroom extracts, medicinal and exotic mushrooms could have an influence on the human exposure to chemical hazards. The cultivation of exotic mushrooms in the Netherlands has increased; however exotic mushrooms are often imported. Increased import from Asia could affect the food safety due to differences in practices and standards in Asia. Innovations in mushroom processing to increase self-life, enriched mushrooms, new packaging, and other new processing techniques may also have consequences for the chemical food safety of the products. Alternatives for compost or casing soil are expected to be used in the future; these could contain other chemical hazards, which could accumulate in mushrooms. Therefore, compost and casing soil should be checked on chemical hazards. Experts mentioned that more preventive hygiene practices (like disinfection) will be used in mushroom cultivation, which could positively influence the food safety. Overall, it is important to keep track of trends and new developments in the mushroom market.

Samenvatting

Dit rapport beschrijft de chemische gevaren die kunnen voorkomen in de paddenstoelenproductieketen; dit betreffen zowel wilde als gekweekte paddenstoelen. De resultaten uit dit rapport zullen door Bureau Risicobeoordeling & onderzoek van de NVWA (NVWA-BuRO) gebruikt worden als input voor hun integrale ketenanalyse van de paddenstoelenketen. Op basis van deze analyse zal NVWA haar monitoringsprogramma risicogebaseerd gaan invullen.

De long list van chemische gevaren die kunnen voorkomen in de fruitketen
In dit onderzoek werd een literatuurstudie uitgevoerd om de chemische gevaren te kunnen identificeren die van boer-tot-bord kunnen voorkomen in de paddenstoelenketen, in zowel gekweekte als wilde paddenstoelen. Naast literatuuronderzoek werd gebruik gemaakt van nationale monitoringsgegevens die verkregen werden uit de KAP-databank (2013-2017) en RASFF-meldingen (2013-2018). Op basis van het literatuuronderzoek en de monitoringsgegevens werd een zogenaamde 'long list' opgesteld van chemische gevaren die kunnen voorkomen in paddenstoelen. De long list bestaat uit de volgende stofgroepen die via de compost, bestaande uit gips, paarden- en kippenmest en stro, kunnen voorkomen in gekweekte paddenstoelen: zware metalen en spoorelementen, pesticiden en residuen van diergeneesmiddelen. Verder kunnen tijdens de kweek van de paddenstoelen nog residuen van pesticiden voorkomen, reinigings- en desinfectiemiddelen en perchloraat. Daarnaast werd nicotine aangetroffen zowel in wilde als in gekweekte paddenstoelen. In wilde paddenstoelen kunnen ook stoffen voorkomen die via de omgeving ophopen in de paddenstoelen, zoals zware metalen en spoorelementen, radionucliden en persistente organische verontreinigende stoffen (POP's). Natuurlijke toxinen (voornamelijk amatoxinen) kunnen voorkomen in bepaalde giftige wilde paddenstoelen, die soms per abuis geplukt worden. Tijdens de verwerking van wilde en gekweekte paddenstoelen kunnen smaakversterkers en kleurstoffen gebruikt worden evenals reinigings- en desinfectiemiddelen en perchloraat. Daarnaast kunnen procescontaminanten gevormd worden. Tijdens transport en opslag van de paddenstoelen kunnen mycotoxinen gevormd worden. Tevens kunnen allergenen aanwezig zijn in paddenstoelen.

De intermediate list van geprioriteerde chemische gevaren in de fruitketen
Op basis van alle beschikbare informatie werd de long list van chemische gevaren geprioriteerd om tot een intermediate list van chemische gevaren in de paddenstoelenketen te komen. Deze intermediate list bevat stoffen die regelmatig gevonden werden in paddenstoelen en/of gevonden werden boven de wettelijke limieten evenals niet-toegelaten stoffen. In sommige artikelen werden verhoogde concentraties zware metalen (1 mg As/kg, 6 mg Cd /kg, >1 mg Pb/kg, 0.25-0.37 mg Hg/kg), platinum groep elementen (PGE's; Pt > 5 mg/kg) en aluminium (17-19 mg/kg) gerapporteerd in gekweekte paddenstoelen uit China, Polen en Spanje. Deze stoffen werden daarom opgenomen in de intermediate list. Voor *Agaricus* (witte champignons, kastanjechampignons en portobello's), de meest gegeten paddenstoelen in Nederland, werden geen hoge concentraties van deze stoffen aangetroffen. De concentraties zware metalen en spoorelementen kunnen aanzienlijk hoger zijn in wilde paddenstoelen dan in gekweekte paddenstoelen indien de concentraties van deze stoffen in de omgeving hoog zijn. Daarom kunnen de concentraties in wilde paddenstielen soms de gezondheidskundige richtwaarden (health based guidance values; HBGV's) overschrijden.

De wettelijke ML's voor radionucliden werden niet overschreden voor gekweekte paddenstoelen. Afhankelijk van de aanwezigheid van radionucliden in de omgeving kunnen hoge concentraties radionucliden ophopen in wilde paddenstoelen die de ML's overschrijden. In sommige gevallen werden ^{137}Cs, ^{226}Ra, ^{210}Pb en ^{210}Po gevonden in concentraties boven de EU of equivalente limieten; deze stoffen werden daarom opgenomen in de intermediate list voor wilde paddenstoelen.

In Nederland zijn slechts drie pesticiden toegelaten voor gebruik in de paddenstoelenteelt: deltamethrin, procloraz en metrafenon. MRL-overschrijdingen werden echter gevonden voor de volgende pesticiden in gekweekte paddenstoelen: bifenthrin, carbofuran, carbendazim, chlorpyrofos, deltamethrin, fenpropathrin, fipronil, procymidone, tetramethrin, β-cyfluthrin, β-cypermethrin en λ-cyhalothrin. In wilde paddenstoelen werden MRL-overschrijdingen gevonden voor: permethrin, propoxur en tetramethrin. Deze pesticiden zijn daarom opgenomen in de intermediate list. Al deze pesticiden zijn momenteel opgenomen in de multi-methoden die in de nationale monitoring gebruikt worden en zullen daarom gevonden worden als ze aanwezig zijn in paddenstoelen.

Sommige specifieke paddenstoelensoorten kunnen natuurlijke toxines, voornamelijk amatoxinen, bevatten die dodelijk kunnen zijn bij consumptie. Daarom kan het plukken van wilde paddenstoelen riskant zijn, omdat dan toxische paddenstoelen per ongeluk gezien kunnen worden als eetbare paddenstoelen. In de literatuur en in RASFF-meldingen werden amatoxinen soms aangetroffen in paddenstoelen. Deze werden daarom opgenomen op de intermediate list voor wilde paddenstoelen.

In het verleden zijn nicotineconcentraties boven de MRL gevonden in zowel gekweekte als wilde paddenstoelen. De oorzaak hiervan is nog steeds onbekend. Daarom zijn nicotines ook opgenomen in de intermediate list. Desinfectiemiddelen (zoals formaldehyde, trihalomethaan, halo-azijnzuur en chloraat) zijn nodig bij de kweek en verwerking van paddenstoelen. Er zijn momenteel echter weinig data over de aanwezigheid van residuen van deze stoffen. Daarom zijn deze desinfectiemiddelen ook opgenomen op de intermediate list, zodat meer gegevens beschikbaar komen.

Alle stoffen op de intermediate list moeten verder geëvalueerd worden, door de concentraties die gevonden zijn in paddenstoelen te combineren met consumptiegegevens, zodat het mogelijke risico voor de volksgezondheid ingeschat kan worden. Stoffen met een mogelijk gezondheidsrisico en stoffen waarvoor kennis ontbreekt zouden moeten worden opgenomen op de zogenaamde ‘short list’. Deze lijst dient dan als basis voor het opstellen van een risicogebaseerd monitoringsprogramma.

Trends en ontwikkelingen in de fruitketen
Literatuuronderzoek en raadpleging van experts werd gebruikt om opkomende trends te kunnen identificeren die de aanwezigheid van chemische gevaren in de padenstoelenketen kunnen beïnvloeden. Hieruit kwam naar voren dat paddenstoelen perfect passen in de huidige consumententrend rondom gezondheid, duurzaamheid, gemak en plantaardige diëten. Consumententrends zoals het toegenomen gebruik en consumptie van paddenstoelenextracten, medicinale en exotische paddenstoelen kunnen een effect hebben op de aanwezigheid van chemische gevaren. De kweek van exotische paddenstoelen is toegenomen in Nederland; de meeste exotische paddenstoelen worden echter geïmporteerd. Een toename in import vanuit Azië kan de voedselveiligheid beïnvloeden door een verschil in praktijken en heersende voedselveiligheidsstandaarden in Azië. Innovaties in de verwerking van paddenstoelen kunnen de houdbaarheid verbeteren, paddenstoelen verrijken, resulteren in nieuwe verpakkingen en andere procestechnieken. Deze ontwikkelingen kunnen gevolgen hebben voor de voedselveiligheid van de producten. In de toekomst wordt verwacht dat er alternatieven gebruikt gaan worden voor de compost en de dekaarde. Deze kunnen andere chemische gevaren bevatten die kunnen ophopen in de paddenstoel. Daarom zou compost en dekaarde gecontroleerd moeten worden op chemische gevaren. Experts gaven aan dat hygiënepraktijken (zoals desinfectie) in de paddenstoelenteelt verder zullen verbeteren in de toekomst, wat een effect heeft op voedselveiligheid. In het algemeen is het belangrijk om trends en ontwikkelingen in de paddenstoelenketen in de gaten te houden.

1 Introduction

The Netherlands Food and Consumer Product Safety Authority (NVWA) monitors the safety of food and consumer products, health of animals and plants and animal welfare and enforces nature legislation. The main tasks of the NVWA are supervision (inspections and surveillance), risk assessment and risk communication.

NVWA's supervision will be renewed towards a risk-based monitoring in order to better protect the safety of products, animal welfare and the health of animals and plants. Twelve main production chains have been identified in the working area of the NVWA. An assessment of the risks of these production chains will lead to recommendations for inspections and surveillance and possible policy measures to reduce risks.

One of the main supply chains is the fruit and vegetable chain. The mushroom supply chain is a sub-chain. The aim of the current study is to make an inventory of possible chemical hazards in the mushroom supply chain, from farm-to-fork, the so-called long-list of chemical hazards. Based on literature review and monitoring data, this list is then prioritised to identify the most relevant chemical hazards, which were put on the intermediate list. Furthermore, upcoming trends that could influence the presence of chemical hazards were investigated using literature review and expert elicitation.

This information will be used by the NVWA department for Risk Assessment and Research (Bureau Risicobeoordeling & Onderzoek; BuRO) as input for the integral chain analysis for the mushroom supply chain.

2 Materials and Methods

2.1 Research Plan

This research project consisted of the following steps:
1. Literature study on chemical hazards that may occur in the mushroom supply chain (section 2.2).
2. Analysis of available monitoring data of the Netherlands and Rapid Alert System for Food and Feed (RASFF) data (section 2.3).
3. Determination of chemicals with priority based on step 1 and 2 (section 2.4). For these chemical hazards, health based guidance values (such as ADI, ARfD etc.) are indicated (section 2.5).
4. Evaluation of trends and developments within the mushroom supply chain within the next 5 years that may influence the occurrence of food safety hazards based on literature and expert elicitation (section 2.7).

2.2 Literature screening

2.2.1 Literature screening in scientific databases

For the literature screening in scientific databases, 'Scopus' and 'Web of Science' were selected as the most relevant scientific databases to screen for chemical hazards in the mushroom supply chain. The following search string was used to search for relevant literature on chemical hazards in edible mushrooms in the period of 2008-2018 (until 24 July 2018). Detailed information on the selection of relevant research terms and the selections of the relevant scientific databases can be found in Annex 2.

At the start of the project search terms have been determined in agreement with NVWA. Products included are all types of edible mushrooms.

Search string:

#1: Mushrooms
In title:
(Mushroom* OR Agaricus OR Agrimonia OR Agrocybe OR Auricularia OR Boletus OR Clitocybe OR Coprinus OR Cortinarius OR Craterellus OR Flammulina OR Ganoderma OR Grifola OR Gyromitra OR Hericium OR Hydnum OR Hypsizygus OR Lactarius OR Lentinula OR Lentinus OR Lepista OR Morchella OR Pholiota OR Pleurotus OR Rhizopus OR Sparassis OR Stropharia OR Terfezia OR Tremella OR Tricholoma OR Tuber OR Ustilago OR Volvariella OR Agaric OR Agarikusutake OR "Callampa Agaricus" OR Champignon* OR "Cogumelo do Sol" OR Kawariharatake OR Himematsutake OR cremini* OR portobello* OR Matsutake OR "velvet pipoppini" OR "jew's ear*" OR "jelly ear*" OR porcini OR cèpe* OR "shaggy mane*" OR "lawyer's wig*" OR "cortinar webcap*" OR "trompette du mort" OR enoki OR lingzhi OR "hen-of-the-woods" OR maitake* OR "monkey's head*" OR "lion's mane*" OR "bear's head*" OR "hedgehog mushroom*" OR shimeji OR "indigo milk cap*" OR "candy cap*" OR "saffron milk cap" OR shiitake* OR "wood blewit*" OR morel* OR nameko OR "oyster mushroom*" OR "cauliflower mushroom*" OR roundhead* OR truffle* OR "paddy straw mushroom*" OR chanterelle*)

AND #2: Chemical hazards
In title, abstract or keywords:
"Food contamination" OR "Chemical pollutant*" OR "chemical hazard*" OR contamina* OR toxin* OR "toxic substance*" OR "toxic compound*" OR pollutant* OR "agricultural chemical*" OR "chemical compound*" OR "chemical substance*" OR residu*

AND #3: Public health
In title, abstract or keywords:
"Public health" OR "HACCP" OR "Consumer protection" OR Consumer* OR "Food safety" OR "risk assessment*" OR "risk analys*" OR "hazard analys*" OR "Human health*" OR "Health impact" OR "health risk*"

Limited to publication years 2008-2018

All retrieved papers were downloaded into an Endnote file and duplicate references were removed.

The following steps were followed to select relevant publications:

1. Relevance of the publication was determined based on the title and, if needed and available, the abstract. Selection of relevant papers was checked by another scientist for ten percent of the publications. Papers were classified in Endnote as 'relevant', 'maybe relevant' and 'not relevant'.
2. Relevant papers from step 1 were further screened based on abstract, material and methods and conclusion of these publications.
3. Papers considered as relevant in step 2 were analysed using the abstract, material & methods and discussion of the publications. Possible chemical hazards, region and country where these hazards were found, concentrations mentioned, the type and size of the study and the main message of the publications were recorded in an Excel file.
4. Papers analysed in step 3 were used to give an overview of chemical hazards that might be present in mushrooms (see section 3.3). In case many papers were found for a certain chemical hazard, only papers were included that described information for a relevant geographical origin. This was determined based on import data (see section 2.3).
5. Papers considered as 'maybe relevant' were also further screened based on abstract and added to the list of relevant papers when considered relevant.

Hits were considered relevant when chemical hazards for edible mushrooms were mentioned in the publication. Literature considering, among others, tuber (thickened structures in plants), Morelos (a city in Mexico), mushroom substrate use for non-food applications, influence of mushroom substrate on the environment, detoxification by mushrooms, microbiological hazards, positive health effects or the development of analytical methods were considered as not relevant for the purpose of this study.

2.2.2 Literature screening with 'Google'

Additionally, searches were performed with Google on selected relevant websites (Additional information on the selection of these websites can be found in Annex 3). The websites used were the websites of EFSA (http://www.efsa.europa.eu), FAO (http://www.fao.org), BfR (https://www.bfr.bund.de), and FDA (https://www.fda.gov). Three search strings were performed on these four websites:

1. Mushroom AND "food safety"
2. Mushroom AND (contaminant OR residue)
3. Mushroom AND "risk assessment"

When an individual search resulted in more than 200 hits, the last 10 years were selected (2008-2018). When this still resulted in more than 200 hits, only the file type pdf was selected.

The retrieved papers were analysed as described for the scientific papers in section 2.2.1.

2.2.3 Additional searches

The literature search as described in sections 2.2.1 and 2.2.2 in some cases only resulted in a few hits. In order to check whether more information was available for these hazards, additional searches were performed in Scopus for mycotoxins, persistent organic pollutants, allergens, nicotine, flavour enhancers or colourings, processing contaminants and cleaning or disinfectants. The following searches were performed in title, abstract or keywords:

- (mushroom* AND mycotoxin* AND ("food safety" OR hazard* OR risk*))

- (mushroom* AND (“Persistent organic pollutants” OR PAH OR PCB OR dioxin OR PFA OR BFR))
- (mushroom* and allerg*)
- (mushroom* AND nicotine)
- Mushroom* AND (“flavour enhancer*” OR “monosodium glutamate” OR colour*) AND (“food safety” OR hazard* OR risk*) about hazards in mushrooms related to flavour enhancers or colourings
- (mushroom* AND (“processing contaminants” OR furan OR acrylamide OR 3-mcpd))
- (mushroom* AND (cleaning OR disinfect*)

2.3 Data

Dutch monitoring data were obtained from the KAP database for 5 years (2013-2017) and were provided as Excel file by the RIVM. These data included: product name, type of hazard, sampling strategy, number of samples, number of positive measurements, average of positive measurements, maximum found level and for the pesticides the number of measurements > MRL.

RASFF data were obtained for 2013-2018 (till 23-07-2018) https://webgate.ec.europa.eu/rasff-window/portal

2.4 Prioritization

The literature revealed which chemical hazards may occur in mushrooms. Each of these hazards is described in section 3.3, the so-called long list of chemical hazards. Based on information in the retrieved papers and reports regarding detected levels in mushrooms, the most relevant chemical hazards were identified, which is indicated in the conclusion of each section. The information from literature and monitoring data was combined to come to an intermediate list of chemical hazards that are frequently found in mushrooms and/or that are found at levels above the legal limit.

2.5 Product limits and health-based guidance values

For substances in the intermediate list, concentrations found in literature and monitoring data were presented. EU legal limits (MLs) were obtained from the website of the European legislation (eur-lex.europa.eu). MRLs and health based guidance values of pesticides were obtained from the EU pesticide database (ec.europa.eu/food/plant/pesticides/eu-pesticides-database). Other health based guidance values were obtained from reports of food safety authorities: EFSA, JECFA, WHO and US EPA. Additionally, relevant information from EFSA reports on the hazards of the intermediate list were described. EFSA opinions were available for arsenic, cadmium, lead, mercury, aluminium, formaldehyde, chlorate and nicotine.

2.6 Evaluation of trends

Trends that might have an effect on chemical hazards in the mushroom supply chain were searched in Google using each of the following search strings:
- trends AND mushroom
- “consumer trends” AND mushroom AND Europe
- trade and mushroom and trend
- trend and mushroom and innovations

Furthermore, trend reports from Dutch banks (e.g. Rabobank, ABN-AMRO) were searched. In case trends were mentioned in the literature search performed on chemical hazards in mushroom (section 2.2), these were also added.

Moreover, experts in the field (mushroom cultivators, compost and casing soil industry, processing industry, research and branch organisations) were consulted to identify trends in the mushroom supply chain that can affect food safety. For this purpose, a pre-defined questionnaire (in Dutch) was drafted in cooperation with Wageningen Food & Biobased Research (WFBR) (Annex 4). Eighteen experts working in the mushroom supply chain were contacted to fill in the questionnaire or invited to have an interview by phone.

Furthermore, in collaboration with WFBR the Innova Database (Innova) was used to determine trends in new product introductions. Innova Market Insights collects all new product introductions, collecting all information available on the package into the Innova Database. Information about the product that is not mentioned on the package is consequently not in the database, nor is there a log on how long the product has stayed on the market. The database shows an overview of the trend in products in the past years. In the database, products can be sorted on ingredients, packaging, year, country etc. Furthermore, the team from Innova makes regular updates on trends they note in several of the categories they work in. The search in the database was performed using a free text search on mushrooms. The search was restricted to products introduced in the Netherlands between 2007 and 2017, while also relevant reports of the Innova team were studied.

3 Results

3.1 Literature study

The literature search resulted in 154 hits using Scopus and 88 hits using Web of Science. From the total of 241 publications, duplicates were removed (72) resulting in a total of 169 publications. These were evaluated in step 1 of selecting relevant papers as described in section 2.2.1 resulting in 113 relevant papers, 5 maybe relevant papers (of which 1 paper finally was added to the relevant papers) and 52 not relevant papers. Step 2 of selecting relevant papers as described in section 2.2.1 resulted in 97 relevant papers and thereby 68 not relevant papers.

Ten percent of the papers was checked by another scientist for their relevance (see Annex 5). This showed that 68% of the papers were evaluated the same. For the other papers, the screening was performed more conservative meaning that papers were initially evaluated as relevant, which turned out not to be relevant. The outcome was discussed in order to align the evaluation and further sharpen the relevance criteria.

The searches performed with Google on the websites of EFSA, FAO, FDA and BfR resulted in 25 relevant hits about chemical hazards for edible mushrooms. Detailed description of number of hits found per website can be found in Annex 6.

The additional searches performed in Scopus for mycotoxins, persistent organic pollutants, allergens, and nicotine, flavour enhancers or colourings, processing contaminants and cleaning or disinfectants resulted in total in 8 additional relevant hits. Details can be found in Annex 7.

A short overview of mushroom production and import is given in the next section. This information is taken into account for selecting the papers that are used to describe the chemical hazards that may occur in the mushroom supply chain (see section 3.2 for a description of the mushroom production and import data). Section 3.3 gives a summary of the outcome of the literature review.

3.2 Mushroom production and import data

Mushrooms on the Dutch market are either cultivated, wild or medicinal. The latter were not part of this research. Cultivated mushroom account for 54%, medicinal mushrooms for 38% and wild mushrooms account for 8% of the worldwide mushroom industry (Royse, 2017). *Lentinula* spp. (shiitake, 22%), *Pleurotus* spp. (oyster mushrooms, with 5 to 6 species, 19%), *Auricularia* spp. (black fungus or wood-ear mushroom, 17%), *Agaricus* spp. (white button mushroom, 15%), and *Flammulina* spp. (Enoki, 11%) are the five genera of mushrooms covering 85% of the mushroom supply worldwide (see Table 1). 87% of the global mushroom production is in China. Almost all consumption of mushrooms in China, EU and India in 2013 was from domestic production (Royse, 2017). In Europe, the white button mushroom is by far the most consumed mushroom, while in China, other mushroom species are consumed.

The Netherlands was the fourth country in the production of *Agaricus* spp. in 2013 (Royse, 2017). Within Europe, the Netherlands and Poland are the main producers of mushrooms. The last 10 years the production in Poland has enormously grown, mainly on the fresh market (Rabobank, 2016). In total, 75% of the mushroom production of the Netherlands is exported (Rabobank, 2016). Top exporting countries are China, Spain, India, Egypt and Belgium (MarketResearchFuture, 2018). Import to the Netherlands is small and primarily includes wild and exotic mushrooms. When imported, the mushrooms are mainly from Poland, Balkan, Russia, China, South-Africa, US and Canada (expert interview).

The sector in the Netherlands includes mainly the cultivation of white button mushroom (90%), chestnut mushrooms are the largest group of the other mushrooms (Rabobank, 2016). Consumption in the Netherlands coincides with this: the most consumed mushrooms are white button mushrooms. The most relevant other consumed mushrooms are chestnut mushrooms, oyster mushrooms and shiitakes (expert interview).

The cultivation of the white button mushroom takes place in controlled conditions in cultivation cells. Compost is used as breeding ground, which is covered with a layer of casing soil. The compost industry makes compost from plaster, horse and chicken manure and straw, which are first fermented and pasteurised, after which the compost is grown with mushroom fungi (expert interview). For the cultivation of mushrooms, several other substrates can be used, for example wheat straw, gypsum, oak and beach sawdust or chicken manure (Niedzielski et al., 2017).

Peat casing material is added on top of the compost on the mushroom beds in cultivation cells. When the first flush of mushroom is harvested, the same mushroom beds can be used for a second flush. After this, the cells are cleaned, pasteurized and emptied; then a new cultivation process can start (expert interview).

In the Netherlands, mushroom production can be divided in production for the fresh markets (hand picking, 40%) and production for the industry market (mechanical picking, 60%). Industry market consists of canned, frozen and dried mushrooms (expert interview).

Table 1 *Overview of the main produced mushrooms worldwide*

Scientific name	Common name
Lentinula	Shiitake
Pleurotus	oyster mushrooms
Auricularia	black fungus or wood-ear mushroom
Agaricus	champignon, white button mushroom, chestnut mushroom, portabella
Flammulina	Enokitake, enoki

3.3 Overview of chemical hazards

This section summarizes scientific literature and reports describing chemical hazards found in various cultivated and wild mushrooms. All possible hazards found are included; these comprise the long list of chemical hazards that may occur in mushrooms.

3.3.1 Heavy metals and other elements

3.3.1.1 Heavy metals in cultivated mushrooms

Mushrooms are known to accumulate cadmium, lead, mercury and arsenic from the soil (Schlecht and Säumel, 2015). For cultivated mushrooms, heavy metals may be taken up from the soil/compost used. In Europe, maximum levels are set for cadmium and lead in mushrooms for the species *Agaricus bisphorus* (among others white button mushroom), *Pleurotus osteratus* (oyster mushroom) and *Lentinula edodes* (shiitake) as described in Regulation (EC) 1881/2006. The maximum level for cadmium is 0.2 mg/kg wet weight (ww), which, considering the usual 10% dry matter content, corresponds to 2 mg/kg dw. The maximum level for lead is 0.3 mg/kg ww, or 3 mg/kg dw. For other mushrooms, the maximum level for cadmium is 1.0 mg/kg ww and for lead 0.10 mg/kg ww.

For many species of cultivated mushrooms, studies from Spain (Rubio et al., 2018), Germany (Schlecht and Säumel, 2015), Poland (Drewnowska et al., 2017; Niedzielski et al., 2017), and United States (Seyfferth et al., 2016) showed that cadmium levels were below the EU legal limit of 0.2 mg/kg ww. The studies from China (Fang et al., 2014; Pei et al., 2015; Niedzielski et al., 2017), showed that cadmium levels were below the Chinese legal limit of 0.3 mg/kg ww. Occasionally, high cadmium levels can be found as Mleczek et al. (2017) showed in a study where cadmium levels were found up to 6.15 mg/kg dw in *Lentinula edodus* samples obtained from 2009-2015 from Poland. These cadmium levels were indicated as levels of concern as these could lead to exceedance of the provisional tolerable weekly intake (PTWI, 7 μg/kg bw/day) of JECFA of cadmium (Mleczek et al., 2017). US Total diets study data from 2006-2013 showed that the mean cadmium level was 0.006 mg/kg in raw mushroom (FDA, 2017). Mushrooms are mentioned by EFSA as food products that can contain high levels of cadmium. However, they are less consumed than other products containing cadmium (such as cereals, cereal product, vegetables, nuts and pulses, starchy roots or potatoes and meat and meat products) and therefore mushrooms are not major contributors to cadmium exposure (EFSA, 2009a). Higher dietary exposure is expected for regular consumers of wild mushrooms as average concentrations found in wild mushrooms were 0.446 mg/kg ww, while in cultivated mushrooms, the average concentration was 0.163 mg/kg ww (EFSA, 2009c).

Studies from Poland (Mleczek et al., 2017; Niedzielski et al., 2017), China (Pei et al., 2015; Niedzielski et al., 2017), US (Seyfferth et al., 2016), Spain (canned mushrooms) (Rubio et al., 2018), Nigeria (Nnorom, 2011) and Germany (Schlecht and Säumel, 2015) showed that lead levels were found below the EU maximum level (0.3 mg/kg). A study from China showed that in 2.6% of several fresh cultivated mushroom samples the lead levels were above the Chinese maximum allowance of 1 mg/kg for fresh mushrooms (Fang et al., 2014). US FDA Total diets study data from 2006-2013 showed that trace amounts of lead were only detected in 2 out of 32 raw mushroom samples, with a mean value of 0.001 mg/kg (FDA, 2017).

This study from China also showed that 4.8% of the samples exceeded the Chinese maximum allowable concentration for mercury, which is 0.1 mg/kg and 0.2 mg/kg for fresh and dry mushrooms, respectively (Fang et al., 2014). The EU MRL of mercury for cultivated fungi is 0.05 mg/kg and for wild fungi is 0.5 mg/kg. Three other studies from China studied mercury in *Lentinus edodes*, *Macrocybe gigantea* and *Boletus*. Mercury levels of 0.25-0.37 mg/kg dm were found in *macrocybe gigantea.* Considering a consumption of only 2-3 times per year, because of availability that depends on the season, this was not considered as a human health concern (Wiejak et al., 2014). Maximum found levels in *Lentinus edodes* were low, 0.013 mg/kg (Pei et al., 2015), while the mercury levels in *Botelus* were exceeding the Chinese maximum levels (Yang et al., 2015). Mercury was detected in trace amounts in 7 out of 16 raw mushroom samples, with a mean of 0.001 mg/kg in US FDA Total diets study data from 2006-2013 (FDA, 2017).

Arsenic is a toxic element, which can also easily be accumulated in mushrooms. US FDA Total diets study data from 2006-2013 showed total arsenic detected in all 32 samples, the mean value of arsenic in raw mushrooms was 0.051 mg/kg (FDA, 2017). A review paper by Falandysz and Rizal (2016) gives an overview of total arsenic levels found in all types of mushroom species. Arsenic present in the substrate is the main cause for potential concern. One of the regions in the world with high arsenic levels in the environment is the Yunnan region in China. Some mushrooms that were grown in this area were found to exceed the maximum levels in China (Falandysz and Rizal, 2016). The Chinese maximum allowance for total arsenic is 0.5 mg/kg ww and 1 mg/kg dw. In 12 different cultivated mushroom species from Poland and China, arsenic levels were found between 0.001 and 1 mg/kg dw (Niedzielski et al., 2017). In contrast to previous mentioned studies, the Chinese limits were not exceeded in several cultivated mushroom species in the study of Fang et al (2014). Concentrations of arsenic and inorganic arsenic in several species from the US showed low levels (inorganic arsenic: 0-63 μg/g dw), that did not lead to exceedance of tolerable intakes (0.3 μg/day for inorganic arsenic, US EPA) considering US consumption data (Seyfferth et al., 2016). Mushrooms, except for Agaricus spp., bought in shops in Canada contained levels of total arsenic ranging between 0.02 and 1.3 mg/kg dw), which could be of risk for consumers (Nearing et al., 2014). Experiments with several substrates for *Pleurotus florida* from Iran resulted in the conclusion that arsenic was an element of concern for human consumption (Khani et al., 2017). A culturing experiment in Poland with *Agaricus bisporus, Pleurotus ostreatus, Pleurotus eryngii* and *Hericium erinaceus* showed that accumulation of total arsenic is low in A. bisphorus. However, arsenic concentrations were clearly higher in the other species and consumption these other species could be of concern. Accumulation is dependent on the arsenic concentration present in the substrate and the mushroom species (Mleczek et al., 2016c).

Three studies specifically investigated *Lentinus edodus*. The highest concentration of total arsenic was 1.3 mg/kg in samples from China (Pei et al., 2015). Another study from China showed that inorganic arsenic was close to the maximum Chinese level in half of the samples (Chen et al., 2018). For *Lentidus edodes* samples from Poland, it was concluded that consumption would significantly contribute to the intake of arsenic (Mleczek et al., 2017).

3.3.1.2 Other elements in cultivated mushrooms

Besides heavy metals, trace elements and other elements can also accumulate in mushrooms, such as platinum (Pt), aluminium (Al) and selenium (Se). The substrate used for cultivation can be contaminated with these elements when collected from polluted areas (Niedzielski et al., 2017). In 12 less popular cultivated mushrooms, relatively high levels of platinum group elements (PGEs) were found compared to the regularly consumer mushrooms such as *Agaricus* and *Pleurotus* species. Particularly, high Pt levels were found, exceeding 5 mg/kg dw. (Niedzielski et al., 2017). Rare earth elements (REEs) were also studied, but not found to be high in the studied mushroom species compared to the Chinese maximum in food of 0.7 mg/kg (Niedzielski et al., 2017). Rare earth elements in *Lentinula edodes* were also clearly lower than levels observed in other food products, including vegetables. However, they did exceed the provisionally set Chinese limit of 0.7 mg/kg (Mleczek et al., 2017). Rare earth elements are not regulated in many countries, but get slightly more attention in the scientific literature.

Canned mushrooms grown in Spain contained high levels of Al of 16.8-19.3 mg/kg ww. Considering consumption of 200 gram of mushrooms per day, this will significantly contribute to the intake of Al (maximum intake limits is 1 mg/kg bw/week, EFSA) (Rubio et al., 2018). Higher concentration of aluminium of 5-10 mg/kg observed in mushrooms were also mentioned in the EFSA opinion on the safety of aluminium from dietary intake (EFSA, 2008).

Most edible mushroom species contain low selenium levels based on a review of 190 mushroom species (Falandysz, 2008). However, mushrooms could also be cultivated on selenium-enriched substrates, leading to high selenium content. Consumption of 5-7 gram of mushrooms leads to an intake of about the recommended daily allowance (RDA) of selenium of 55-75 µg Se/day (Falandysz, 2008; Bhatia et al., 2013; Kasuya et al., 2014).The Tolerable Upper Intake level (UL) for adults set by EFSA for selenium is 300 µg/day (EFSA, 2006)

3.3.1.3 Heavy metals in wild mushrooms

Wild mushrooms are only a small contributor to the total mushroom consumption, but they may contain high levels of heavy metals (Árvay et al., 2015). Accumulation of heavy metals in wild mushrooms depends on the environment. Wild mushrooms from contaminated environments will contain much higher levels of heavy metals. Levels of heavy metals were also found to be higher in wild mushrooms from urban regions due to the traffic (Chen et al., 2009; Mleczek et al., 2016a) or due to industrial activities, like former mining areas (Záhorcová et al., 2016).

Asia is an important import region for the Netherlands with China as the leading mushroom producing country. Most information from literature on wild mushrooms was from China. Heavy metals found in wild mushrooms from China to be of possible concern (exceeding regulatory limits or significant contribution of consumption to HBGVs) were cadmium (Chen et al., 2009; Zhu et al., 2011; Yin et al., 2012; Liu et al., 2015; Sun et al., 2017; Yang et al., 2017; Su et al., 2018), lead (Chen et al., 2009; Zhu et al., 2011; Yin et al., 2012; Liu et al., 2015; Sun et al., 2017), mercury (Chen et al., 2009; Wiejak et al., 2014; Falandysz et al., 2015a; Yang et al., 2015; Yang et al., 2016) and arsenic (Yin et al., 2012; Liu et al., 2015; Zhang et al., 2015).

Data of heavy metals in wild mushrooms collected in Europe were from several countries: Germany, Greece, Italy, Poland, Belarus, Serbia, Slovakia, Slovenia, Spain, and Turkey. Concerning levels of cadmium considering contribution to the TWI (2.5 µg/kg bw, EFSA) or compared to EU ML) were found in wild mushrooms in 11 studies (Giannaccini et al., 2012; Petkovšek and Pokorny, 2013; Árvay et al., 2014; Árvay et al., 2015; Schlecht and Säumel, 2015; Melgar et al., 2016; Mleczek et al., 2016a; Stefanović et al., 2016b; Záhorcová et al., 2016; Falandysz et al., 2017a; Falandysz et al., 2017b), while two studies indicated levels of cadmium that were not of human health concern (Aloupi et al., 2012; Jarzyńska and Falandysz, 2012).

Lead levels of potential concern (considering contribution to the TWI (0.025 mg/kg bw, JECFA) or compared to EU ML) in wild mushrooms collected in Europe were found in nine studies (Giannaccini et al., 2012; Petkovšek and Pokorny, 2013; Árvay et al., 2014; Árvay et al., 2015; Schlecht and Säumel, 2015; Mleczek et al., 2016a; Stefanović et al., 2016b; Falandysz et al., 2017a; Falandysz et al., 2017b), while in five studies levels were found that were not found to be of human health concern (García et al., 2009; Aloupi et al., 2012; Jarzyńska and Falandysz, 2012; Mleczek et al., 2013a; Türkmen and Budur, 2018).

Consumption of wild mushrooms from Europe was considered to be of concern for human health (considering the TWI of 4 μg/kg bw) in 11 studies analysing European wild mushrooms (Melgar et al., 2009; Chojnacka et al., 2012; Falandysz et al., 2012a; Giannaccini et al., 2012; Mleczek et al., 2013b; Árvay et al., 2014; Falandysz et al., 2014; Árvay et al., 2015; Falandysz, 2016; Krasińska and Falandysz, 2016; Falandysz et al., 2017b), seven studies did not find levels of concern for human health for mercury (consumption compared with TWI) (Chudzyński et al., 2009; Falandysz et al., 2012b; Mleczek et al., 2013a; Dryzałowska and Falandysz, 2014; Falandysz, 2014; Kojta and Falandysz, 2016; Saba et al., 2016).

Measured arsenic levels in four studies (Giannaccini et al., 2012; Stefanović et al., 2016a; Falandysz et al., 2017a; Falandysz et al., 2017b) were of no concern (consumption compared with PTWI), only one study on wild mushrooms collected in extremely polluted areas in Poland observed arsenic levels that could pose a human health risk (Mleczek et al., 2015).

Occasionally, very high levels of heavy metals were found in wild mushrooms. However, the availability of wild mushrooms depends on the season, so wild mushrooms are not regularly consumed (Falandysz et al., 2014; Wiejak et al., 2014).

3.3.1.4 Other elements in wild mushrooms

Iron, nickel and manganese levels were found in high levels in wild mushrooms collected in Turkey (Türkmen and Budur, 2018). Potassium was found to be high in *Marcrolepiota procera* collected in Serbia (Stefanović et al., 2016a). Uranium was found to be high in wild mushrooms at one site compared to other sites in Poland (Falandysz et al., 2017a). Some wild mushrooms can also contain high levels of selenium (Falandysz, 2008; Giannaccini et al., 2012). These above mentioned elements were considered to be high in mushrooms considering that average consumption will significantly contribute to ULs or that several grams of consumption will lead to exceedance of the RDA (e.g. potassium 560%) (Falandysz, 2008; Stefanović et al., 2016a; Falandysz et al., 2017a; Türkmen and Budur, 2018).

REEs and PGEs were studied in wild mushrooms from Poland and no significant accumulation of these elements was found (Mleczek et al., 2016b; Falandysz et al., 2017c). The levels of these elements are likely lower than in other food products and therefore consumption of these mushrooms will not significantly contribute to the dietary exposure of these elements. However, the mean levels found in the mushrooms studied exceeded the Chinese maximum level, as set for vegetables for REEs of 0.7 mg/kg ((this limit is used because there is no EU limit) (Mleczek et al., 2016b).

Conclusion

In general, concentrations of heavy metals and other elements were much lower in cultivated mushrooms than in wild mushrooms. Overall, the levels of heavy metals or other elements found in cultivated mushrooms were not of human health concern. *Agaricus* (white button mushrooms, chestnut mushrooms and portobellos), which are the main consumed mushrooms in the Netherlands, did not contain levels of heavy metals above the legal limits. A few studies showed alarming levels of heavy metals (cadmium, lead, mercury and arsenic), PGEs and aluminium in other cultivated mushroom species; these mushrooms were mainly from Eastern Europe and China.

The levels of heavy metals and other elements were shown to be higher in wild mushrooms compared to cultivated mushrooms. However, this depends on the levels present in the environment. Local levels of heavy metals in the environment can be high and consequently consumption of wild mushrooms with high levels may exceed levels of concern (HBGVs).

3.3.2 Radionuclides

Mushrooms can accumulate radionuclides in the same way as they can accumulate heavy metals (Guillén and Baeza, 2014). They can take up radionuclides via airborne disposition or through transfer via the soil. There are many studies addressing radionuclide levels in mushrooms, mostly about radiocaesium. However, there is limited information on radionuclide levels in mushrooms from the main producing mushroom countries.

Mushrooms grown in areas heavily contaminated with radionuclides can accumulate up to ten times higher levels of radionuclides than in areas with background levels. For example, consumption of wild mushrooms from the area of the Chernobyl accident resulted in increased body content of radiocaesium. Restriction of cultivation in that area and prohibiting consumption of wild mushrooms was effective in reducing human exposure to radiocaesium (Guillén and Baeza, 2014).

In general, radionuclide content is lower in cultivated mushrooms than in wild mushrooms, because the substrates used for mushroom cultivation contain less radionuclides. In Europe, the limit for radiocaesium in food products is 600 Bq/kg for agricultural production (Regulation (EC) 733/2008), which can be converted to a limit of 6000 Bq/kg dw (Guillén and Baeza, 2014).

Activity levels equivalent to the EU regulatory value of ^{137}Cs can be used as an indicative limit for other radionuclides which do not have a regulatory limit (Guillén and Baeza, 2014). An exhaustive review was carried out by Guillen et al. (2014) to identify all radionuclides found in wild and cultivated mushrooms. All reported anthropogenic radionuclide values were well below the legal EU and Japanese limits (Japanese limits were 2000 Bq/kg for radioiodine, 500 Bq/kg for radiocaesium, 100 Bq/kg for uranium, and 10 Bq/kg for plutonium) or derived indicative limits, except for ^{137}Cs. Furthermore, maximum ^{226}Ra, ^{210}Pb and ^{210}Po values found in wild mushrooms were above the respective indicative equivalent limit based on the EU limits for ^{137}Cs (279, 113, 65 Bq/kg dw, respectively) (Guillén and Baeza, 2014).

Radionuclide data of the Netherlands of 1800 food products showed that 14 samples contained ^{137}Cs, of which one mushroom sample contained a level of 74 Bq/kg ^{137}Cs, which is below the legal limit (RIVM, 2016). Dutch radionuclide measurements in 2010-2013 showed that in seven wild mushroom samples ^{137}Cs was detected, all levels being below the legal limit (Brandhoff et al., 2016). Radionuclide analytical results of ^{137}Cs, ^{40}K and ^{90}Sr in raw mushrooms were reported in the Total Diet Study of the US Food and Drug Administration from 2006 to 2014. ^{137}Cs was not detected in the analysed samples (n=11) and the mean value of ^{40}K was 107.5 Bq/kg, with a max of 147.6 Bq/kg (n=11). The mean value of ^{90}Sr was 0.029 with a max of 0.32 Bq/kg (FDA, 2015).

Radionuclide levels of ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra were also analysed in cultivated mushrooms (*Agaricus, Pleaurtus* and *Lentinula*) in Brazil. Detected levels for ^{137}Cs were between 1.45-10.6 Bq/kg, for ^{40}K between 461-1535 Bq/kg, for ^{226}Ra between 14-66 Bq/kg, and for ^{228}Ra between 6.2-54.2 Bq/kg. It was indicated that all these levels were below maximum limits following Brazilian legislation (de Castro et al., 2012). Moreover, these results from North and South America were all below calculated limits equivalent to the EU radiocaesium limit.

Collected dried shiitake samples from the Japanese market showed values of 192-596 Bq/kg, which in some cases exceeds the Japanese limit of 500 Bq/kg, but is just below the European limit (Tsuchiyama et al., 2015). Monitoring data of the first five years after the Fukushima nuclear accident compromise 20.000 mushroom samples of which 2.6% of the samples exceeded the regulatory limit. Almost all exceedances were found in the mushroom samples from the pre-market, while post-market samples showed comparably lower radionuclide levels. Therefore, it was concluded that the monitoring campaign was successful (Prand-Stritzko and Steinhauser, 2018).

Radiocaesium levels observed in wild mushroom samples collected in several European countries and Turkey showed that all values were lower than 401 Bq/kg dw, which is below the European limit (Karadeniz and Yaprak, 2010; Gwynn et al., 2013; Betti et al., 2017). The ^{40}K levels were between 588-2024 Bq/kg dw. Wild mushroom samples from Norway had ^{210}Pb and ^{210}Po levels of 2.5-3.3 and

4.7-198 Bq/kg dw, respectively (Gwynn et al., 2013). The levels of ^{210}Po exceeded the limit as calculated by Guillen et al., 2014.

Wild and cultivated pantropical mushrooms *Macrocybe gigantea* were collected in China and ^{137}Cs, ^{40}K and ^{226}Ra were determined. The concentration of ^{137}Cs was 5.4 Bq/kg, ^{40}K showed 2-3 times higher concentrations and the median activity concentration of ^{226}Ra was below 66 Bq/kg dm. Radionuclides levels found in these mushrooms were considered not to be of safety concern (Falandysz et al., 2015b).

Two papers studied the effect of processing on the levels of radionuclides in mushrooms. These showed that radionuclides can be reduced by different kitchen procedures such as washing, boiling, frying, and adding of salt (Guillén and Baeza, 2014; Steinhauser and Steinhauser, 2016).

Conclusion
Mushrooms are accumulators of radionuclides. However, in general, levels in cultivated mushrooms will not exceed the regulated maximum limits for radionuclides. Dependent on the presence of radionuclides in the environment, wild mushrooms could accumulate radionuclides. Occasionally, high values above the EU or indicative limits were found in wild mushrooms of ^{137}Cs, ^{226}Ra, ^{210}Pb and ^{210}Po.

3.3.3 Pesticides

In general, the use of plant protection products is low in mushroom cultivation in the Netherlands. However, mushrooms may also contain residues due to pesticides used on cereals that enter into for example the compost used for mushroom cultivation. In the Netherlands, only a few pesticides are approved for use in mushroom cultivation. These are the insecticide deltamethrin and the fungicides prochloraz and metrafenon (Ctgb, aurthorised products database 07/12/2018). In recent years, peer review risk assessments were performed and evaluated by EFSA for the active substance diflubenzuron, which can be used as insecticide on mushrooms, and for hypochlorite, which can be used as bactericide on mushrooms (EFSA, 2012b, 2012c). Both pesticides are approved for use in Europe (EU pesticides database).

Pesticides can be sprayed directly on the mushrooms or can be premixed with the substrates. Because only a few pesticides are available for use in mushroom cultivation, biological control of insect pests is commonly used by mushrooms growers in Europe (Jess and Schweizer, 2009).

Several pesticide trials performed in Europe revealed that residue levels of prochloraz at the maximum level of good agricultural practices (GAP) (3.5 mg/kg). However, the FAO concluded that long-term and short-term intake of residues of prochloraz from mushrooms was unlikely to pose a human health concern (FAO, 2009).

Mepiquat and chlormequat residues were found in cultivated mushroom samples (mepiquat highest value 0.18 mg/kg, (EFSA, 2016)). This is not due to the use of the substance on mushrooms, but from uptake from the substrate that contains straw that has been treated with this pesticide (EFSA, 2011). Based on European monitoring data of 545 samples, EFSA has derived an optional MRL of 0.09 mg/kg that will not pose a public health concern (EFSA, 2016).

In fresh chanterelles from Lithuania, Russia and Belarus detected levels of DEET (N,N-diethyl-3-methylbenzamide) were up to 1 mg/kg. BfR performed a risk assessment for acute exposure to DEET using German and European consumption data, and has concluded that consumption of these mushroom does not pose a human health concern (BfR, 2009).

Cyromazine has been widely used as insecticide in vegetables and mushrooms. Examples of use have been found in Spain, Swiss, France and the US. Codex has set an MRL for cyromazine in mushrooms of 7 mg/kg (FAO, 2007). A trial with cyromazine performed in China revealed that the residue levels found did not exceed the EU MRL of cyromazine and its metabolite melamine of 10 mg/kg and that consumption of the mushrooms does not pose a concern for human health (Zhao et al., 2018).

For the cultivation of shitakes, a high temperature and humidity are needed. Therefore, pesticides are often used to control insect infestations and a variety of diseases. Two registered and commonly used pesticides for shiitake cultivation in China are thiabendazole and β-cyfluthrin. Four other pesticides are also used in China: carbendazim, procymidone, bifenthrin, and λ-cyhalothrin (Liu et al., 2016). These six pesticides were used in pesticide trials in shiitake cultivation. General procedures of cultivation and pesticide use were followed. The final residue levels of these six pesticides sprayed and premixed with the substrate were below the Chinese MRLs for edible fungi. However, β-cyfluthrin, procymidone, bifenthrin, and λ-cyhalothrin levels exceeded the European MRLs. The estimated daily intake of all pesticide residues by mushroom consumption were lower than the respective ADIs and therefore it was concluded that there is a low human health concern (Liu et al., 2016).

Another study from China also describes that pyrethroids are used as insecticides for mushroom cultivation; however, they are not registered in China for this purpose. Three cultivation trials of *Auricularia polytricha* were conducted following standard procedures with the pyrethroids, bifenthrin, fenpropathrin, λ-cyhalothrin, β-cypermethrin, and deltamethrin. Almost all residue levels found were above the respective MRLs as established in Europe, Japan or China (Xiao et al., 2018).

A significant number of samples of dried white mushrooms from China have been observed to contain residue levels of carbofuran above the MRL value of 0.01 mg/kg. The European Spice Association (ESA) requested for a higher import tolerance value for carbofuran. However, EFSA concluded that the MRL of 0.01 mg/kg should be maintained to prevent exceedance of the ARfD of 0.15 μg/kg bw (EFSA, 2014c). Pesticide residue data from the EU showed that wild fungi samples with MRL exceedance rates higher than 10% were found for tetramethrin, propoxur and permethrin. For tetramethrin the exceedance rate was the highest (55% for samples originating from China, n=11) (EFSA, 2011).

US FDA Total Diet Study from 2004-2005 showed pesticide residue levels in raw mushrooms of benomyl (5 out of 8 samples ≥LOQ with a mean level of 0.14 mg/kg), diazinon (2 out of 8 samples ≥LOQ, 0.0006 mg/kg, o-phenylphenol (1 out of 8 samples ≥LOQ, 0.004 mg/kg), and thiabendazole (7 out of 8 samples ≥LOQ, 0.073 mg/kg). Only trace amounts ≤LOQ were detected for cis- and trans-permethrin in 1 out of 8 samples (FDA, 2006).

Ten mushroom farms in South Africa were included in an evaluation of food safety management systems. This revealed that the mushroom farms had an average to advanced food safety management system. Regarding pesticides, most farms used common approved pesticides and followed general procedures. Most farms were sampled for pesticide residues in mushrooms once per month (Dzingirayi and Korsten, 2016).

Conclusion
In the Netherlands, only three pesticides are approved for use in mushroom cultivation. In other countries, also other pesticides are used and approved. Residue levels of pesticides used on mushrooms in Asian countries showed exceedances of the EU MRLs for: bifenthrin, carbofuran, carbendazim, chlorpyrifos, deltamethrin, fenpropathrin, fipronil, procymidone, tetramethrin, β-cyfluthrin, β-cypermethrin and λ-cyhalothrin. MRL exceedances in wild mushrooms were found for permethrin, propoxur and tetramethrin.

3.3.4 Persistent organic pollutants

Persistent organic pollutants (POPs) are lipophilic compounds that can persist and accumulate in the environment.

POPs can also accumulate in foods, primarily in fatty tissues of animals. Therefore, main human intake is from food products of animal origin, like meat, eggs, milk and fish. Mushrooms may become contaminated with POPs through uptake of these substances via the environment.

In the EU maximum levels for certain POPs, more specifically dioxins and both dioxin-like and non-dioxin-like polychlorinated biphenyls (PCBs), are established for products of animal origin and for vegetable oils and fats (Regulation (EC) 1881/2006). For vegetables, only action levels for dioxins and

DL-PCBs are established. Probably as a result, only limited data are available for the presence of POPs in mushrooms.

An additional search for POPs was performed in Scopus, however only limited data is available for the presence of POPs in mushrooms.

Dioxin contamination was evaluated in Japanese fresh and frozen vegetables in 2002. Mushrooms were included in this study. Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) and coplanar polychlorinated biphenyls (Co-PCBs) were measured in enoki, maitake and shiitake mushrooms. PCDFs were detected in maitake and shiitake mushroom with levels of 0.001 and 0.014 pg TEQ/g prepared weight. PCDDs and Co-PCBs were not detected in the analysed mushrooms samples (Amakura et al., 2003).

According to EFSA (2018), the perfluoroalkylated substance (PFASs) PFOS has been detected in wild but not in cultivated mushrooms. PFOA was not detected in any of the reported samples. At present there are no regulatory limits for these substances in food (EFSA, 2018).

Residues of chlorinated organic pesticide can still be present in the environment, although in most parts of the world they were withdrawn from the market 40 years ago. People are mostly exposed to these compounds via food. In wild mushroom samples collected in Poland, chlorinated hydrocarbon residues, DDT, DDE, DDD and γ-HCH were detected. However, the levels were low and consumption will not exceed the Provisional Tolerable Daily Intake (10 μg/kg bw/ day, PTDI) for DDT as set by the FAO (2005), indicating that the consumption of these mushrooms does not pose a human health risk (Gałgowska et al., 2012).

Conclusion
Given the lipophilic property of most POPs, they are not likely to be present in mushrooms. Additional searches in Scopus did also not show that lipophilic POPs are likely to be present in mushrooms. This may be different for PFASs but current data suggest that these substances only occur in occasionally in samples of wild mushrooms.

3.3.5 Mycotoxins

Mycotoxins are produced by fungi. During storage, fungi may contaminate mushrooms. Wet and warm environments stimulate fungal growth, which may result in mycotoxin formation.

An additional literature search on mycotoxins was performed in Scopus, which showed that there are limited data available about the presence of mycotoxins in mushrooms. Two studies were retrieved that measured mycotoxin levels in mushrooms. In dried mushroom samples from Nigeria no EU regulated mycotoxins were detected (Ezekiel et al., 2013). In *Botelus edulis* samples from Italy, aflatoxin B1, B2, G1, G2, and ochratoxin A were all found to be below the limit of detection (Lorini et al., 2008).

Conclusion
There are no indications that mycotoxins would be of concern in mushrooms.

3.3.6 Natural toxins

Mushrooms can contain natural toxins. Collecting wild mushrooms for consumption can therefore be risky, because toxic mushrooms can be mistaken for widely consumed edible species. Mushroom toxicity is in 80% of the cases associated with amatoxins (Clarke et al., 2012). In many European countries, like France, Germany, Poland and Turkey, it is common to collect wild mushrooms for consumption. Therefore, BfR for instance has published a brochure to inform consumers about mushroom collection and to help to distinguish edible and toxic mushrooms. In 2017, 20 cases were reported of mushroom poisoning in the Netherlands (NVIC, 2018). BfR has reported 27 cases of mushrooms poisoning in 2015 of which two were fatal (BfR, 2016). In general, an amount of 50 grams of toxic mushrooms can be lethal for adults. Consumption of 5-7 gram of the death cap mushroom

(*Amanita phalloides*) can already be fatal (Clarke et al., 2012). For several European countries and Turkey up to 320 cases of mushroom poisoning per year were reported (WHO, 2003b; EFSA, 2007). Several recent case reports also described severe incidences of mushroom poisoning due to mistakenly collected wild toxic mushrooms (Evans et al., 2012; Garcia et al., 2015). When indicated these reports were about amatoxins.

Agaritine is a natural compound occurring in white button mushrooms. This compound has been described as being a potential carcinogen in mouse studies; however, this is contradicted in other studies. No carcinogenic effects have been observed after consumption of mushrooms in mice, rats or humans. Therefore, in a critical review it was concluded that consumption of white button mushrooms and other edible mushrooms is not of concern for human health (Roupas et al., 2010). The agaritine content in mushrooms is reduced by cooking, boiling and preservation (Mohamed, 2012).

Conclusion
Some specific mushroom species contain natural toxins, mainly amatoxins, that can be lethal. Therefore, collection of wild mushrooms for consumption can be risky, since toxic mushrooms can be mistaken for edible species.

3.3.7 Nicotine

In 2008, nicotine was detected in dried *Botelus edulis* mushrooms, truffles and chanterelles. These wild mushrooms mainly originated from China (EFSA, 2009b). The levels were higher than the default EU MRL of 0.01 mg/kg fw. Therefore, the EFSA has assessed if nicotine concentrations up to 0.5 mg/kg were of risk for human health. Long-term exposure scenarios indicated nicotine exposures well below the ADI of 0.008 mg/kg bw/day. However, acute intake of high consumers in Europe exceeded the ARfD. EFSA concluded that a residue level of 0.53 mg/kg is not safe (EFSA, 2009b). Consequently, EFSA proposed an alternative temporary MRL for fresh and dried wild mushrooms of 0.036 and 1.17 mg/kg, respectively. The cause of the presence of nicotine in the mushrooms is still unknown. It could originate from use of pesticides that can contain nicotine. However, in Europe these pesticides are not allowed anymore. Another reasoning is that nicotine could be endogenously formed in mushrooms. The third option is that cross contamination with nicotine from tobacco could occur during pickling, storage or drying of the mushrooms (EFSA, 2009b; Cavalieri et al., 2010; Schindler et al., 2015). Nicotine was also detected in 3 samples of cultivated mushrooms from the Netherlands and Belgium in 2013 (RASFF data) (Schindler et al., 2015).

Conclusion
In the past, nicotine levels have been found in mushrooms. The cause of the presence of nicotine is still unknown.

3.3.8 Processing contaminants

During heating steps, like frying and drying, processing contaminants can be formed. Furan is formed when a product is heated and contains ascorbic acid, amino acids, carbohydrates, unsaturated fatty acids and carotenoids (EFSA, 2017b).

In canned mushrooms in the US, furan levels of 4.1 µg/kg were detected in samples taken by the FDA in 2004 (FDA, 2004). These levels found in mushrooms are relatively low compared to breakfast cereals and dry bread products, in which furan levels up to 400 µg/kg were found. Consumption of coffee and breakfast cereals contribute the most to dietary exposure to furan in adults and children, respectively. Mushrooms are not mentioned as an important contributor to dietary exposure to furan (DTU, 2009). This was confirmed by EFSA, who concluded that depending on the age of the consumer the main contributors to dietary intake of furan are ready-to-eat meals, grain and grain-based products and coffee(EFSA, 2017a).

Additional literature searches were performed to find more information on processing contaminants in mushrooms. No other data were found in these additional searches.

Conclusion
Processing contaminants are not often found or mentioned in relation to mushrooms. Therefore, potential food safety concerns related to processing contaminants are expected to be low for mushrooms.

3.3.9 Cleaning agents and disinfectants

After harvesting each batch of mushrooms, the production area is cleaned and disinfected. Furthermore, when mushrooms are processed after harvest they are washed before or after slicing to remove residual substrate and to decrease microorganisms.

Formaldehyde is an authorised substance that can be used as disinfectant for growing facilities and equipment in the cultivation of mushrooms (Claeys et al., 2009; Dzingirayi and Korsten, 2016). Formaldehyde is carcinogenic via inhalation; however, limited data are available on the effects of ingestion. The use in mushroom cultivation is allowed in the Netherlands, but for instance not in Belgium although exemption of the Belgium regulation is possible for mushroom substrates and fertilizers. Furthermore, other authorised biocides can also contain formaldehyde. There are no European standards for the use of formaldehyde in mushroom cultivation (Claeys et al., 2009). Claeys et al., 2009 evaluated if formaldehyde was present in cultivated mushrooms from Belgium, the Netherlands and Poland and if these could pose a risk for consumers. Formaldehyde concentrations were between 0.07 and 0.65 mg/kg, which are generally lower than reported levels in other fruits and vegetables. Formaldehyde intake due to mushroom consumption was estimated to be 1000 times lower than the TDI as set by the WHO for drinking water (WHO, 2006) and the RfD (USEPA, 1990) taking into account Belgium consumption data. Therefore, it was concluded that monitoring of formaldehyde should not have the highest priority (Claeys et al., 2009).

The main sanitizer applied on mushrooms during processing is hydrogen peroxide. The microbial loading on mushrooms is reduced while minimizing browning when hydrogen peroxide is used in combination with UV (Murray et al., 2015).

Disinfection by-products were found in canned vegetables including mushrooms in Spain. This is caused by the water used in their processing. Trihalomethanes and haloacetic acids were found in canned mushrooms in the same concentrations as found for other canned vegetables like peas, beans, and corn (Cardador and Gallego, 2017). Chlorate can also be used to disinfect water, which can be used in processing of mushrooms. Chlorate levels were also found in several fruits and vegetables, among others in mushrooms in Germany (Kettlitz et al., 2016).

Conclusion
An additional search on cleaning and disinfectants was performed in Scopus; however, there is only limited information available on the use of cleaning and disinfection agents and possible concentrations of residues in mushrooms. However, disinfection is very important for the cultivation facilities and equipment used for mushrooms. Furthermore, cleaning and disinfection of mushrooms is also important before or during processing. Therefore, possible presence of disinfection residues (like formaldehyde, trihalomethanes, haloacetic acids and chlorate) cannot be excluded.

3.3.10 Allergens

Mushrooms do not belong to the 14 major allergens, which should be labelled as an allergen following legislation. However, there are several cases reported of allergic or intolerance reactions to specific types of mushrooms.

Consumption of shiitake mushrooms can lead to an allergic cutaneous reaction in sensitive persons, which is called shiitake dermatitis. Symptoms are a red skin, linear erythematous eruptions with papules and plaques, in some cases it can be a severe reaction. The reactions are probably caused by the natural ingredient lentinan (BfR, 2004; Stephany et al., 2016).

Several other recent cases are described for other types of mushrooms; these are rare cases in sensitized persons (Fischer et al., 2017; Michas et al., 2017).

Conclusion
Overall, allergic reactions to mushrooms are rare.

3.3.11 Other chemical hazards

The literature research identified some other chemical hazards in relation to mushrooms: Polycyclic Aromatic Hydrocarbons (PAHs), perchlorate, flavour enhancers and colourants.

Sixteen PAHs were analysed in wild and cultivated mushrooms from Nigeria. The concentrations ranged from 0.02-3.37 ng/g. All mushrooms with detected PAH concentrations had a Margin of Exposure (MOE) above 10.000 considering the respective $BMDL_{10}$ (0.17-0.49 mg/kg bw/ day, EFSA, 2008), which can be considered to be of low concern for public health (Igbiri et al., 2017).

Perchlorate can enter food from fertilisers, via contaminated water used for irrigation or when perchlorate is illegally used for disinfection purposes. However, no perchlorate residues have been found in mushrooms in the health assessment of perchlorate residues in foods by BfR (BfR, 2013).

Flavour enhancers and colourants can be used in canned mushrooms, which was discussed by the 34th session of the joint FAO/WHO food standards programme Codex Alimentarius Commission in 2011. Because of reservations on the use of monosodium glutamate as flavour enhancer and caramel IV as colouring agent, the Codex "standard for certain canned vegetables" was adopted for mushrooms (FAO/WHO, 2011).

Additional searches were performed on these other chemical hazards in Scopus, but no further results were found. The information obtained for PAHs, perchlorate, flavour enhancers and colourants did not indicate that these other chemical hazards should be put in the intermediate list.

3.4 Monitorising data

Dutch monitoring data from 2013-2017 of non-pesticides included only selective samples in button mushrooms, shiitakes, oyster mushrooms, chanterelles and mushrooms (not specified) on cadmium, lead, and mercury (see Table 2). Positive measurements were found for 48% of all selective samples (60 out of 124): 82% positive samples for cadmium, 19% for mercury and 44% for lead. The average of the positive measurements was not exceeding the EU maximum level for cadmium of 0.2 mg/kg. However, the highest level of cadmium found in mushrooms (not specified) was 0.21 mg/kg, and in shiitakes, it was 0.27 mg/kg. The highest levels for lead were not exceeding the EU maximum level of 0.3 mg/kg. Furthermore, the highest levels of mercury found in chanterelles, oyster mushrooms, button mushrooms and shiitake were all 0.01 mg/kg, which is clearly below the Chinese limit of 0.1 mg/kg and the EU MRL of mercury for cultivated fungi of 0.05 mg/kg and for wild fungi of 0.5 mg/kg. Only in mushrooms (not specified), 2 samples out of 16 were positive, with a maximum value of mercury of 0.33 mg/kg.

Dutch monitoring data from 2013-2017 on pesticides in mushrooms showed 26 positive results out of 882 samples (see Table 2). Only one MRL exceedance was found. This was for the pesticide chlorpyrifos in button mushrooms. The measured level of chlorpyrifos was 0.09 mg/kg, which is above the MRL of 0.05 mg/kg.

RASFF notifications from 2013-2018 (https://webgate.ec.europa.eu/rasff-window/portal) related to chemical hazards in mushrooms are shown in Table 3. Most notifications were on pesticides (43%); the total number of these notifications was 20. The origin of the mushrooms with notification on heavy metals, radionuclides and natural toxins was from countries in Eastern Europe. The notifications on radionuclides were all for wild mushrooms. The notifications on undeclared sulphite and pesticide residues were from Europe and Asia. Sulphites concentration >10 mg/kg should be declared on the label as allergens (Regulation (EC) 1169/2011) and following the EU additives legislation (Regulation (EC) 1333/2008) sulphites used as additive should be declared by their chemical name. The notified pesticides were fipronil, carbendazim, carbofuran, tetramethrin and nicotine.

Table 2 *Dutch monitoring data (KAP) in mushrooms for 2013-2017*

Chemical hazards	Average of positive measurements (mg/kg)	Highest level reported (mg/kg)	Number of measurements	Percentage positive measurements / total measurements (%)	Exceedances found >MRL or > ML
Heavy metals[a]					
cadmium	0.25	0.67	45	82.2%	yes
mercury	0.27	0.37	47	19.1%	yes
lead	0.16	0.24	32	43.8%	
Pesticides[b]					
2,4,6-trichlorophenol	0.01	0.01	121	0.8%	
carbendazim (sum)	0.14	0.14	129	2.3%	
chlorpyrifos	0.12	0.12	127	1.6%	yes
endosulfan (alpha+beta+sulphate)	0.02	0.02	2	50.0%	
endosulfan-sulphate	0.02	0.02	2	50.0%	
esfenvalerate	0.02	0.02	2	50.0%	
nicotine	0.02	0.02	128	3.1%	
permethrin	0.01	0.01	121	0.8%	
procloraz	0.04	0.14	121	8.3%	
thiabendazole	0.02	0.02	129	1.6%	

[a] For heavy metals, the sampling strategy for all samples was selective.

[b] For pesticides, the sampling strategy was not indicated or suspect. For carbendazim 8 samples were suspect, for chlorpyrofos 6 samples were suspect (the MRL exceedance did not come from these 6 samples), for endosulfan all samples were suspect and for thiabendazole, 8 samples were suspect. For all other samples, the sampling strategy was not indicated.

Table 3 *RASFF notifications on chemical hazards for mushrooms from 2013-2018*

Notifications	Number of notifications	Percentage of total notifications (%)
biotoxins	**3**	**15.0%**
presence of poisonous mushrooms	2	10.0%
presence of poisonous mushrooms - Amanita phalloides	1	5.0%
food additives and flavourings	**3**	**15.0%**
sulphite undeclared	3	15.0%
heavy metals	**2**	**10.0%**
arsenic	1	5.0%
mercury	1	5.0%
pesticide residues	**9**	**45.0%**
fipronil	1	5.0%
unauthorised substance carbendazim	1	5.0%
unauthorised substance carbofuran	1	20.0%
unauthorised substance nicotine	4	5.0%
unauthorised substance tetramethrin	1	20.0%
Radionuclides	**4**	**15.0%**
too high level of radioactivity	3	5.0%
unauthorised irradiation	1	100.0%
Total	**20**	**100.0%**

Conclusion
Some of the mushroom samples in the Dutch monitoring data exceeded the legal limit for cadmium. From the 10 pesticides measured in the Dutch monitoring, the MRL was only exceeded for chlorpyrifos. RASFF data showed most notifications on pesticides that were not authorised: fipronilcarbendazim, carbofuran, tetramethrin and nicotine were notified. Other notifications were on natural toxins, undeclared sulphite, heavy metals and radionuclides.

3.5 Prioritized hazards

3.5.1 Long list

Hazards that might be present in mushrooms are mentioned in the long list of hazards. This long list contains all hazards mentioned in literature (Table 4). Based on the Dutch monitoring data in mushrooms the pesticides 2,4,6-trichlorophenol, chlorpyrifos, endosulfan (alpha, beta, sulphate), endosulfan-sulphate, esfenvalerate, permethrin, prochloraz and thiabendazol were added to the long list. Undeclared sulphite and the pesticides fipronil and tetramethrin were added to the long list based on RASFF notifications for mushrooms.

3.5.2 Intermediate list

Hazards that are frequently found in mushrooms, found above the EU legal limits or reference values as well as unauthorised substances encountered in mushrooms based on literature study and monitoring data are included in the intermediate list of hazards. A rationale for including chemical hazards in this list is indicated below and in Table 4.

The literature research revealed that levels of heavy metals and other elements can be higher in wild mushrooms compared to cultivated mushrooms, as local levels of heavy metals in the environment may be high. Consequently, the levels in wild mushrooms could be of human health concern. A few studies showed levels of heavy metals, PGEs and aluminium in cultivated mushroom species (abnamro, 2012; Fang et al., 2014; Wiejak et al., 2014; Mleczek et al., 2017; Niedzielski et al., 2017); these mushrooms were not cultivated in the Netherlands. *Agaricus* (white button mushrooms, chestnut mushrooms and portobellos), which are the main consumed and cultivated mushrooms in the Netherlands, did not contain high levels of heavy metals. Therefore, the heavy metals arsenic, cadmium, lead and mercury and aluminium and PGEs were added to the intermediate list. Wild mushrooms are in bold for heavy metals, because occurrence is higher in wild mushrooms than in cultivated mushrooms.

Legal maximum limits for radionuclides were not exceeded in cultivated mushrooms. However, dependent on the presence of radionuclides in the environment, wild mushrooms can contain high radionuclides levels. Occasionally, levels for ^{137}Cs, ^{226}Ra, ^{210}Pb and ^{210}Po in wild mushrooms were found that exceeded the EU ML for ^{137}Cs or equivalent ML to ^{137}Cs for the other radionuclides. (Guillén and Baeza, 2014). Therefore, these radionuclides were added on the intermediate list for wild mushrooms.

Pesticides that exceeded the EU MRLs according to literature or monitoring data and unauthorised pesticides were put on the intermediate list. MRL exceedances were found for; bifenthrin, carbofuran, chlorpyrofos, deltamethrin, fenpropathrin, procymidone, β-cyfluthrin, β-cypermethrin, λ-cyhalothrin, (Liu et al., 2016; Xiao et al., 2018), carbendazim (Liu et al., 2016), fipronil, tetramethrin (RASFF) permethrin and propoxur (EFSA, 2011). Some of these pesticides are not approved in the Netherlands (as indicated in Table 5). Currently, only three pesticides are approved for use in mushroom cultivation in the Netherlands.

Some specific wild mushroom species contain natural toxins, mainly amatoxins, as found in literature (WHO, 2003b; EFSA, 2007; Clarke et al., 2012; Evans et al., 2012; Garcia et al., 2015) and RASFF notifications. These amatoxins can be lethal. Therefore, this plant toxin is also on the intermediate list.

In the past, nicotine levels above the MRL have been found in wild and cultivated mushrooms (EFSA, 2009b). The cause of the presence of nicotine is still unknown. As a result, nicotine was added to the intermediate list.

Disinfection agents (like formaldehyde, trihalomethanes, haloacetic acids, and chlorate) are needed in cultivation and processing of mushrooms (Claeys et al., 2009; Kettlitz et al., 2016; Cardador and Gallego, 2017). However, data are limited and more data are needed on the possible presence of disinfection residues. Therefore, these disinfection agents were added on the intermediate list.

Table 4 *Prioritized hazards in the mushroom supply chain*

Long list hazards that might be present in mushrooms	Intermediate list hazards that are frequently found and/or above legal limits	Product type	Rationale for inclusion on the intermediate list
Heavy metals			
Arsenic	Arsenic	**wild** and cultivated mushrooms	>ML (China) in literature (section 3.3.1) and RASFF
Cadmium	Cadmium	**wild** and cultivated mushrooms	>ML (EU) in literature (section 3.3.1) and Dutch monitoring data
Lead	Lead	**wild** and cultivated mushrooms	>ML (EU) in literature (section 3.3.1)
Mercury	Mercury	**wild** and cultivated mushrooms	>ML (China) in literature (section 3.3.1), RASFF and Dutch monitoring data
Other elements			
Aluminium	Aluminium	wild and cultivated (canned) mushrooms	According to literature a high contribution of mushrooms to the total dietary intake of Al (section 3.3.1)
Iron	PGEs	wild and cultivated mushrooms	According to literature, frequently found compared to other elements (section 3.3.1)
Manganese			
Nickel			
Platinum group elements (PGEs)			
Potassium			
Rare earth elements (REEs)			
Selenium			
Uranium			
Radionuclides			
^{137}Cs	^{137}Cs	wild mushrooms	> EU ML in literature (section 3.3.2) and RASFF
^{210}Pb	^{210}Pb	wild mushrooms	>Equivalent ML to ^{137}CS in literature (section 3.3.2)
^{210}Po	^{210}Po	wild mushrooms	>Equivalent ML to ^{137}CS in literature (section 3.3.2)
^{226}Ra	^{226}Ra	wild mushrooms	>Equivalent ML to ^{137}CS in literature (section 3.3.2)
^{228}Ra			
^{40}K			
^{90}Sr			
Pesticides			
2,4,6-trichlorophenol			
Benomyl			
Bifenthrin	Bifenthrin	cultivated mushrooms	>MRL in literature (section 3.3.3)

Long list hazards that might be present in mushrooms	Intermediate list hazards that are frequently found and/or above legal limits	Product type	Rationale for inclusion on the intermediate list
Carbendazim	Carbendazim	cultivated mushrooms	Unauthorised in EU and found in RASFF and literature (section 3.3.3)
Carbofuran	Carbofuran	cultivated mushrooms	>MRL in literature (section 3.3.3) and RASFF
Chlormequat			
Chlorpyrifos	Chlorpyrifos	cultivated mushrooms	>MRL in Dutch monitoring data
Cyromazine			
DEET			
Deltamethrin	Deltamethrin	cultivated mushrooms	>MRL in literature (section 3.3.3)
Diazinon			
Diflubenzuron			
Endosulfan (alpha+beta+sulphate)			
Endosulfan-sulphate			
Esfenvalerate			
Fenpropathrin	Fenpropathrin	cultivated mushrooms	>MRL in literature (section 3.3.3)
Fipronil	Fipronil[c]	cultivated mushrooms	Unauthorised in EU and found in RASFF
Hypochlorite			
Mepiquat			
Metrafenon			
o-Phenylphenol			
Permethrin	Permethrin	Wild mushrooms	>MRL in literature (section 3.3.3)
Procloraz			
Procymidone	Procymidone	cultivated mushrooms	>MRL in literature (section 3.3.3)
Propoxur	Propoxur	Wild mushrooms	>MRL in literature (section 3.3.3)
Tetramethrin	Tetramethrin	Wild and cultivated mushrooms	Unauthorised in EU and found in RASFF and literature (section 3.3.3)
Thiabendazole			
β-cyfluthrin	β-cyfluthrin	cultivated mushrooms	>MRL in literature (section 3.3.3)
β-cypermethrin	β-cypermethrin	cultivated mushrooms	>MRL in literature (section 3.3.3)
λ-cyhalothrin	λ-cyhalothrin	cultivated mushrooms	>MRL in literature (section 3.3.3)
POPs			
Dioxins			
DL-PCBs			
DDD			
DDE			
DDT			
PFAS			
λ-HCH			
Mycotoxins			
Aflatoxin B1, B2, G1, G2			
Ochratoxin A			

Long list hazards that might be present in mushrooms	Intermediate list hazards that are frequently found and/or above legal limits	Product type	Rationale for inclusion on the intermediate list
Natural toxins			
Amatoxins	Amatoxins	wild mushrooms	Found in literature (section 3.3.6) and RASFF
Processing contaminants			
Furan			
Nicotine	Nicotine	wild and cultivated mushrooms	>MRL in literature (section 3.3.7), RASFF and Dutch monitoring data
Cleaning agents and disinfectants	Disinfectants		Possible residues can be found, but data is limited (section 3.3.9)
Formaldehyde	Formaldehyde	cultivated mushrooms	Idem
trihalomethanes,	Trihalomethanes,	cultivated mushrooms	Idem
haloacetic acids	haloacetic acids	cultivated mushrooms	Idem
chlorate	Chlorate	cultivated mushrooms	Idem
Allergens			
Shiitake dermatitis			
Sulphite			
Other chemical hazards			
PAHs			
Colourants (caramel IV)			
Flavour enhancers (monosodium glutamate)			
Perchlorate			

3.6 Information on concentrations and toxicity of the prioritized hazards

For chemical hazards in the intermediate list, concentrations found in literature and monitoring data are presented in Table 5. EU legal limits (MLs), MRLs and health based guidance values are also presented in the table. Additional relevant information from EFSA reports on the hazards of the intermediate list are described in the paragraphs below. EFSA opinions were available for arsenic, cadmium, lead, mercury, aluminium, formaldehyde, chlorate and nicotine. The ARFDs and ADIs for the prioritised pesticides are included in Table 5.

Table 5 *Intermediate list of prioritized hazards in the mushroom supply chain*

Chemical hazards	Mushroom type	Dutch monitoring (KAP 2013-2017)				RASFF (2013-2018)	Literature	EU legal limit	Health based guidance values[c]		Approval in EU
		Average of pos. meas. (mg/kg)	Max. level (mg/kg)	Total number of measurements	Pos. meas. / total (%)	mg/kg[a]	Max level (mg/kg)[a]	mg/kg[a]	Chronic µg/kg bw/day	Acute µg/kg bw/day	
Heavy metals											
arsenic	wild and cultivated	N	N	N	N	110.00	1.0 (cultivated, Poland and China, (Niedzielski et al., 2017))	N	0.3-8 (BMDL01 (EFSA, 2014a)	N	
cadmium	wild and cultivated	0.25	0.67	45	82%	N	6.15 mg/kg dw (*Lentinula edodus*, Poland, *(Mleczek et al., 2017)*)	0.2 (*Agaricus bisphorus, Pleurotus osteratus, Lentinula edodes*) 1 (fungi)[b] (EU 1881/2006)	2.5 µg/kg bw (TWI, (EFSA, 2009a))	N	
lead	wild and cultivated	0.16	0.24	32	19%	N	> 1 (fresh samples from China, (Fang et al., 2014))	0.3 *Agaricus bisphorus, Pleurotus ostreatus, Lentinula edodes*) 0.1 (fungi)[b] (EU 1881/2006)	0.5 (dietary intake value corresponding to BMDL01 (EFSA, 2012d)	N	
mercury	wild and cultivated	0.27	0.37	47	44%	0.64	0.25-0.37 (cultivated, China, (Wiejak et al., 2014))	N	4 µg/kg bw (TWI,(EFSA, 2012e))	N	
Other elements											
aluminium	wild and cultivated (canned)	N	N	N	N	N	16.8-19.3 (canned, Spain, (Rubio et al., 2018))	N	1 mg/kg bw/week (PTWI, WHO & TWI, EFSA) (EFSA, 2008)	N	
PGEs	wild and cultivated	N	N	N	N	N	Pt> 5 mg/kg dw (cultivated, Poland and China (Niedzielski et al., 2017))	N	N	N	

Chemical hazards	Mushroom type	Dutch monitoring (KAP 2013-2017)				RASFF (2013-2018)	Literature	EU legal limit	Health based guidance values[c]		Approval in EU
		Average of pos. meas. (mg/kg)	Max. level (mg/kg)	Total number of measurements	Pos. meas. / total (%)	mg/kg[a]	Max level (mg/kg)[a]	mg/kg[a]	Chronic µg/kg bw/day	Acute µg/kg bw/day	
Radionuclides											
^{137}Cs	wild	N	N	N	N	803 Bq/kg	Conc. > EU legal limit in wild mushrooms (Guillén and Baeza, 2014)	600 Bq/kg (post-Chernobyl, EU 733/2008) 1250 Bq/kg (future accidents, EU 2016/52)	N	N	
^{210}Po	wild	N	N	N	N	N	Conc. > equivalent limit to EU legal limit of 137Cs (Guillén and Baeza, 2014)	N	N	N	
^{210}Pb	wild	N	N	N	N	N	Conc. > equivalent limit to EU legal limit of 137Cs (Guillén and Baeza, 2014)	N	N	N	
^{226}Ra	wild	N	N	N	N	N	Conc. > equivalent limit to EU legal limit of 137Cs (Guillén and Baeza, 2014)	N	N	N	
unspecified radioactivity						765.1 and 10755 Bq/kg					
Pesticides									**ADI[d]**	**ARfD[d]**	**EU[d]**
bifenthrin	cultivated	N	N	N	N		> MRL (Liu et al., 2016; Xiao et al., 2018)	0.01	15	30	approved
carbendazim	cultivated	0.14	0.14	129	2.3%	3.70	< MRL (Liu et al., 2016)	1	20	20	not approved
carbofuran	cultivated	N	N	N	N	0.06	>MRL (EFSA, 2014c)	0.01	0.15	0.15	not approved
chlorpyrifos	cultivated	0.12	0.12	127	1.6%		N	0.05	1	5	approved
deltamethrin	cultivated	N	N	N	N		>MRL (Xiao et al., 2018)	0.05	10	10	approved

Chemical hazards	Mushroom type	Dutch monitoring (KAP 2013-2017)				RASFF (2013-2018)	Literature	EU legal limit	Health based guidance values[c]		Approval in EU
		Average of pos. meas. (mg/kg)	Max. level (mg/kg)	Total number of measurements	Pos. meas. / total (%)	mg/kg[a]	Max level (mg/kg)[a]	mg/kg[a]	Chronic µg/kg bw/day	Acute µg/kg bw/day	
fenpropathrin	cultivated	N	N	N	N		>MRL (Xiao et al., 2018)	0.01	30	30	not approved
fipronil	cultivated	N	N	N	N	0.51	N	0.005	0.2	9	not approved
permethrin	Wild	N	N	N	N		> MRL (EFSA, 2011)	0.05	N	N	not approved
procymidone	cultivated	N	N	N	N		> MRL (Liu et al., 2016)	0.01	2.8	12	not approved
propoxur	Wild	N	N	N	N		>MRL (EFSA, 2011)	0.05	0.02	N	not approved
tetramethrin	Wild and cultivated	N	N	N	N	1.40	>MRL (EFSA, 2011)	0.01	N	N	not approved
β-cyfluthrin	cultivated	N	N	N	N		>MRL (Liu et al., 2016)	0.02	3	20	not approved
β-cypermethrin	cultivated	N	N	N	N		>MRL (Xiao et al., 2018)	0.05	N	N	not approved
λ-cyhalothrin	cultivated	N	N	N	N		> MRL (Liu et al., 2016; Xiao et al., 2018)	0.02	2.5	5	approved
Natural toxins											
amatoxins	wild	N	N	N	N	presence notified	many cases of mushroom poisoning were reported (WHO, 2003b; EFSA, 2007; Clarke et al., 2012; Evans et al., 2012; Garcia et al., 2015)	N	N	N	
Cleaning agents and disinfectants											
formaldehyde	cultivated	N	N	N	N	N	0.07-0.65 (Claeys et al., 2009)	N	150 (TDI, WHO drinking water, (WHO, 2003a))	N	
Trihalomethanes	cultivated	N	N	N	N	N	Use described (Cardador and Gallego, 2017)	N	N	N	

Chemical hazards	Mushroom type	Dutch monitoring (KAP 2013-2017)				RASFF (2013-2018)	Literature	EU legal limit	Health based guidance values[c]		Approval in EU
		Average of pos. meas. (mg/kg)	Max. level (mg/kg)	Total number of measurements	Pos. meas. / total (%)	mg/kg[a]	Max level (mg/kg)[a]	mg/kg[a]	Chronic µg/kg bw/day	Acute µg/kg bw/day	
haloacetic acids	cultivated	N	N	N	N	N	Use described (Cardador and Gallego, 2017)	N	N	N	
Chlorate	cultivated	N	N	N	N	N	Use described (Kettlitz et al., 2016)	N	3 (TDI, (EFSA, 2015))	36 (EFSA, 2015)	
Nicotine											
nicotine	wild and cultivated	0.02	0.02	128	3.1%	0.18-1.2	0.53 (EFSA, 2009b)	0.04/ 1.2 (dried wild mushrooms)[d]	0.8[d]	0.8[d]	not approved

[a] Levels indicated in mg/kg unless otherwise indicated.

[b] Cultivated and wild mushrooms belong to the category 'fungi' in the legislation

[c] Health based guidance values (HBGVs) are indicated in µg/kg bw/day unless otherwise indicated. HBGVs for chronic exposure are ADIs unless otherwise indicated. HBGVs for acute exposure are ARfD unless otherwise indicated.

[d] For pesticides and nicotine, ADIs, ARfD, and information about the approval of the substance in the EU are extracted from the EU pesticide database (not on use on mushrooms) (http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=homepage&language=EN).

[e] Percentage of number of measurements > MRL/ total measurements for pesticides. For non-pesticides this percentage is total positive/total measurements.

N, no information available.

3.6.1 Arsenic

Food and drinking water are the major exposure routes of arsenic. Inorganic arsenic is more toxic than organic arsenic. Arsenic and inorganic arsenic are classified as carcinogenic to humans (group 1) by the International Agency for Research on Cancer (IARC). The previous set PTWI of 15 µg/kg bw was considered inappropriate by JECFA and EFSA. Therefore, a $BMDL_{01}$ between 0.3-8 µg/kg bw/day for an increased risk of lung-, skin- and bladder cancer, and skin lesions was established by EFSA. The food groups mainly contributing to the dietary exposure of inorganic arsenic are grain based processed products (wheat bread and rolls). Other important contributors are rice, milk and dairy products and drinking water. Mushrooms belong to the vegetable food group, which was not mentioned as main contributor to dietary inorganic exposure (EFSA, 2014a).

3.6.2 Cadmium

EFSA has concluded that the main source of cadmium exposure for the non-smoking general population is food. Cadmium is toxic to the kidney, especially to the proximal tubular cells, where cadmium accumulates (half-life: 10-30 years) and may cause renal dysfunction. This can progress after prolonged or high exposure to renal failure. Cadmium is also classified as human carcinogen Group 1 by the IARC (EFSA, 2009a).

Based on detailed individual food consumption data, a better estimation of dietary intake of cadmium was made by EFSA in 2012. High levels of cadmium (>100 ug/kg) were among others found in fungi (including cultivated and wild mushrooms). However, food consumed in larger quantities contributed the most to the dietary exposure. Across age groups, potatoes (13.2%), bread and rolls 11/7%) and fine bakery wares (5.1%), chocolate products (4.3%), leafy vegetables (3.9%) and water molluscs (3.2%) contributed the most to the dietary exposure of cadmium. An average weekly dietary exposure was estimated at 2.04 µg/kg bw/week and a high exposure (P95) was estimated at 3.66 µg/kg bw/week. The 95^{th} percentile exposure exceeded the TWI (2.5 µg/kg bw) and there is a limited margin between the mean dietary exposure and the TWI. Although the risk for adverse effects on kidney function is low, EFSA concluded that the current exposure to cadmium should be reduced at population level (EFSA, 2012a).

3.6.3 Lead

The major exposure route to lead is via food. Lead can accumulate in the skeleton of the human body; the half-life time in bone is 10-30 years. In blood, the half-life of lead is approximately 30 days. The main target organ of lead toxicity is the central nervous system. Neurotoxicity associated with lead are adverse effects on the short-term verbal memory, fine motor skills, information processing and can cause psychiatric symptoms. In 2010, EFSA has established a new health-based guidance value; the previous established PTWI was concluded to be no longer appropriate. Therefore, a 95^{th} percentile lower confidence limit of the benchmark dose of 1% extra risk ($BMDL_{01}$) of 0.5 µg/kg bw/day for developmental neurotoxicity in young children was identified. The broad food categories contributing the most to lead exposure are: grains and grain products (16.1%), milk and dairy products (10.4%), non-alcoholic beverages (10.2%) and vegetables and vegetable products (8.4%). Lead levels up to 961 ug/kg were found in boletus, a wild mushroom. However, mushrooms were not the main contributors in the vegetable category; these were leafy vegetables (2%), fruiting vegetables (1.8%) and root vegetables (0.9%).

The $BMDL_{01}$ of 0.5 ug/ kg bw /day is lower that the estimated mean exposure for young children. For adults, the respective BMDLs for cardiovascular effects and nephrotoxicity were not exceeded by the estimated mean exposure for adults (EFSA, 2012d).

3.6.4 Mercury

Methyl mercury is the most common form of organic mercury in the food chain, which is present in fish and seafood. In other foods, mercury is present as inorganic mercury. The critical target organ for toxicity of inorganic mercury is the kidney. In line with JECFA, EFSA has established a TWI of 4 µg/kg bw for in organic mercury and a TWI of 1.6 µg/kg bw for methylmercury.

The highest mean total mercury concentrations were detected in fish and other seafood, wild mushrooms and dietary supplements. The mean mercury levels of wild mushroom samples of Poland were between 45-280 µg/kg dw. Major contributors to dietary intake of organic mercury are the food groups fish and other seafood, non-alcoholic beverages and composite food.

The estimated mean exposures to inorganic mercury and organic mercury did not exceed the respective TWIs. However, high consumers of fish meat may exceed the TWI (EFSA, 2012e).

3.6.5 Aluminium

Food is the major route of exposure to aluminium for the general population. Aluminium may persist for a long time in the human body before it is excreted via the urine. Aluminium has been shown to be neurotoxic and nephrotoxic. These neurotoxicity and nephrotoxicity studies were used to set a NOAEL, which was used to derive a TWI of 1 mg/kg bw/week. The estimated daily dietary exposure in Europe is 0.2-2.3 mg/kg bw/day. Mean aluminium levels found in mushrooms were in the range of higher concentrations (5-10 mg/kg) compared to other foods. Vegetables (including mushrooms) were considered as one of the major contributors to the dietary aluminium exposure, but no detailed conclusion on for example the contribution of mushrooms could be made, because of lack of detailed information in the used total diet studies. The TWI of aluminium is likely to be exceeded by dietary exposure (EFSA, 2008).

3.6.6 Formaldehyde

Formaldehyde can be used as a disinfectant. However, it is also an important metabolic intermediate that is present in all cells. Formaldehyde levels in food products can vary from 0.1 – 200 mg/kg. EFSA has estimated that the human oral exposure to formaldehyde will not exceed 100 mg/day. This means an intake of 1.4-1.7 mg/kg bw/day for a person of 60-70 kg. EFSA has not derived a HBGV for formaldehyde (EFSA, 2014b). The WHO has derived a TDI for formaldehyde for drinking water in their guidance document, this TDI was set at 150 µg/kg bw/day (WHO, 2003a).

3.6.7 Chlorate

Chlorate can occur in food due to the use of chlorinated water during processing or due to disinfection of processing equipment. The critical effect for chronic exposure is inhibition of iodine uptake. A TDI of 3 µg/kg bw has been established by EFSA. The ARfD was established at 36 µg/kg bw. Chronic exposure of adolescent and adult age classes did not exceed the TDI. However, the TDI was exceeded at P95 intake in infants and toddlers. Chronic exposures are thus of concern for the human health of the younger age groups. The ARfD was not exceeded by the estimated acute exposures for all age groups. Overall, the main contributor to dietary exposure was drinking water. Mushrooms were not indicated in the EFSA opinion (EFSA, 2015).

3.6.8 Nicotine

Nicotine is an acute toxin; it has an effect on the peripheral and central nervous systems, which can cause for example dizziness, salivation and increased heart rate and blood pressure. Nicotine does not accumulate in the human body because of its short half-life. Therefore, preventing acute effects will also prevent chronic effects. Therefore, the ADI is established at the same levels as the ARfD at 0.0008 mg/kg bw/day (EFSA, 2009b). Other relevant information from this EFSA opinion on nicotine in mushrooms has been described in section 3.3.7.

3.7 Trends in the mushroom supply chain

In total, 18 experts were contacted to get information on trends in the mushroom supply chain using a predefined questionnaire (Annex 4). Eight experts were interviewed and additionally four experts sent in the completed questionnaires via email. Most of the experts were first contacted via an expert of Wageningen University & Research, which resulted in a high response rate.

Additionally, trends and developments within the mushroom supply chain were determined based on a Google search as described in section 2.6.

Furthermore, in collaboration with WFBR the Innova Database (Innova) was used to determine trends in new product introductions as described in section 2.6.

3.7.1 Consumer trends

Mushrooms perfectly fit in the current trends of sustainability, health, functional food, convenience, plant-based diet, and local food (CBI, 2016) and expert opinion). Mushrooms contain few saturated fats and many fibres compared to other foods; therefore, it is a product that fits well in the healthy lifestyle trend. Rising health awareness by consumers has a positive impact on the mushroom market and is expected to positively influence the growth of the sector (MarketResearchFuture, 2018).

The Innova data also showed that convenience and health are the two main categories, with resp. 82 and 34 percent of the new mushroom containing introductions from 2007 to 2017 (Innova).

However, linked to the healthy lifestyle trend there is a trend towards raw consumption of food products, which may have consequences on human health. Raw consumption of shiitake has e.g. been linked to cases of acute dermatitis (FAO/WHO, 2016). Mushrooms are also a good source of proteins; therefore it could be part of the solution of the world food problem, which could lead to an increase in mushroom consumption (Rabobank, 2016).

The trend towards more veganism and plant-based is positive for the mushroom market, the increasing demand for meat substitutes will support the market (MarketResearchFuture, 2018). Mushrooms are often used in meat substitutes in the USA; the use is expected to increase in Europe as well (expert opinion).

The trends mentioned above are likely to increase mushroom demand. Experts working in the mushroom sector acknowledged that within the sector stakeholders should collaborate more to take better advantage of these trends of health and plant-based products (expert opinion).

In Europe, the total consumption of mushrooms is stable (Rabobank, 2016). Consumption of canned mushrooms has decreased in Europe. However canned mushrooms will be increasingly exported worldwide from Europe (expert opinion, (Rabobank, 2016)). The demand for frozen mushrooms is stable or slightly growing (Rabobank, 2016). There is an increased demand of sliced mushrooms and mushrooms in mixes with vegetables (expert opinion). The Innova database also showed that mushrooms are often used in mixtures of vegetables (‘wokmix’, ‘roerbakmix’, ‘soepgroente’) over the last years, while there were also vegetable mixes introduced where mushrooms are the prime ingredient (‘Paddestoelenmix’). The number of new product introductions fluctuated considerably, with a minimum of 1 in 2008 and a maximum of 42 in 2015 (Figure 1) (Innova).

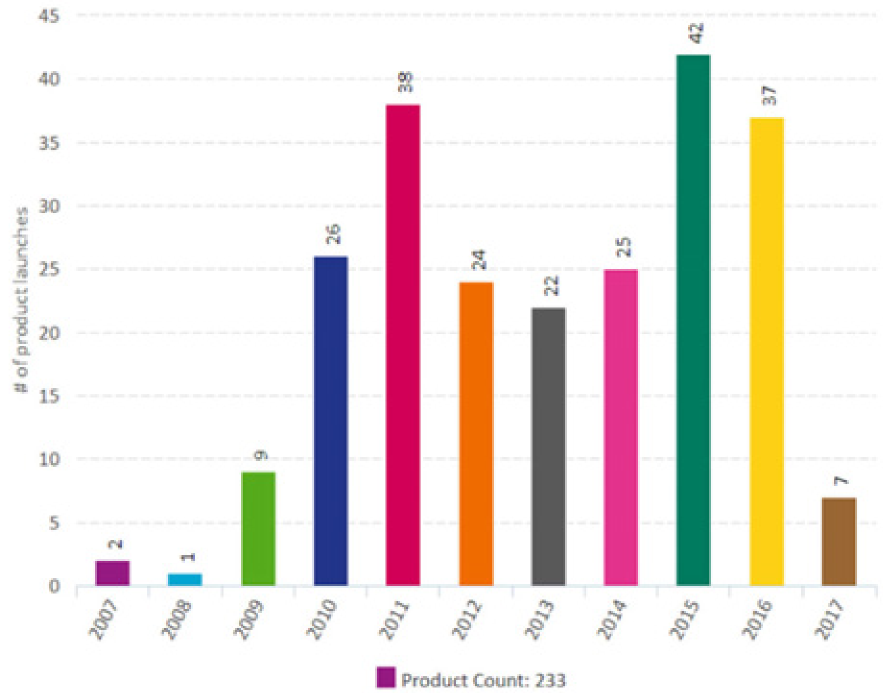

Figure 1 *Product introductions in the Netherlands containing mushrooms, between 2007 and 2017 (Innova)*

Furthermore, a small increase in demand for other mushrooms has been observed, mostly for chestnut mushrooms and a bit for portabellas (Rabobank, 2016), shiitake and oyster mushrooms (expert opinion). The supply of other mushrooms to supermarkets and restaurants is expected to increase further (expert opinion). This is confirmed by the Innova database:, an indulgence trend is seen in the introduction of more exotic mushrooms, such as shiitake, chanterelle and portobello (Innova). Furthermore, an increase in 'home kitchen gardens' for growing mushrooms at home has been observed (Mintel, 2016).

In ready-to-make products, dried mushroom are increasingly used, for example in risotto or in mushroom soup (CBI, 2016). Dried mushrooms or mushroom feet can also be used for mushroom extracts, which are used as flavour enhancer to obtain salt reduction (expert opinion).

Functional mushrooms are mentioned in the top 10 of food trends for 2018 (WholeFoodsMarket, 2018). An increase in medicinal and exotic mushrooms claiming to have health benefits has been observed; they are often sold in powder and drink formats (CBI, 2016) and expert opinion).

The consumer trends mentioned in this section, like the increased demand for sliced mushrooms and mushroom in vegetable mixes and ready-to-make products, primarily influence the microbiological quality of mushrooms. This also counts for the increased consumption of raw mushrooms. The increase in use of extracts and medicinal and exotic mushrooms may influence the presence of chemical hazards.

3.7.2 Innovations in mushroom processing

Experts of the mushroom sector indicated that innovations in the mushroom sector are difficult, because the sector is relatively small (expert opinion). Key focus areas would be innovations through processing (MarketResearchFuture, 2018). New types of processing instead of canning mushrooms are investigated (expert opinion). The packaging of processed mushrooms is expected to change into more attractive packaging, like flexible bags (expert opinion). The Innova data showed that many of the mushroom products are packaged in plastic. Currently, there is a trend towards a decreased use of plastic and packaging material, which may have an especially high impact on the mushroom supply chain (Innova).

There will be investments in research on increasing the shelf life of mushrooms. This is nowadays done on a very small scale, but the potential to grow is large (Rabobank, 2016). For example, cold plasma or activated water can be used (expert opinion).

Innovations are expected on new protein meat replacers based on mushrooms (Rabobank, 2014), expert opinion).

Introduction of mushrooms enriched with selenium, magnesium and vitamin D are investigated (CBI, 2016). Exposure to UV light will increase the level of vitamin D in mushrooms. Among others, Albert Heijn started with the sale of these mushrooms in 2018 (expert opinion).

New processed products with combinations of vegetables and mushrooms with tapenade etc. are expected (expert opinion).

Innovations in mushroom processing to increase self-life, enriched mushrooms, new packaging, and other new processing techniques may have consequences for the chemical and microbiological food safety of the products. It is important to keep track of innovations in the market.

3.7.3 Trends in mushroom compost and casing industry

Peat is often used for the casing soil used in the mushroom cultivation. In the future, it might not be possible to get peat from Germany, because of shortage of peat in Germany. It could be imported from other countries: the Baltic states, Scandinavia or Ireland (expert opinion). Otherwise, alternatives for peat should be used, like stone wool. More research is needed on the possibilities of these alternatives (expert opinion).

It is expected that in the future more organic compost will be used. When the cultivation of mushrooms in the Netherlands will further decrease, the compost industry will try to sell more compost abroad (expert opinion).

Cereals used for the compost of mushroom cultivation can contain pesticide residues, which can end up in mushrooms. Recently, the MRL of chlormequat for cereals is increased from 0.05 mg/kg towards 4 mg/kg, while the MRL for chlormequat in cultivated mushrooms is decreased from 10 mg/kg to 0.9 mg/kg (EU 2017/693) (Eurofins, 2017). This could possibly lead to exceedances of the MRL in cultivated mushrooms. Especially, for oyster mushrooms this is an issue, because more straw is used in the compost for these mushrooms. Therefore, in the Netherlands, a temporary intervention value has been set till 1 July 2019 for chlormequat and mepiquat of 3 mg/kg and 0.3 mg/kg, respectively (NVWA, 2018). The new MRL for mepiquat is 0.09 mg/kg (EU 2017/693).

Alternatives for compost or casing soil could contain other chemical hazards that could accumulate in mushrooms. Changes in MRLs of for example chlormequat and mepiquat could possibly lead to exceedances. Therefore, compost and casing soil should always be checked on chemical hazards, like heavy metals and pesticides.

3.7.4 Trends in mushroom cultivation and trade

Last decades the number of mushroom cultivators has largely decreased in the Netherlands and the number of mushroom cultivators is expected to be further reduced (expert opinion). Poland and Ireland are the main competitors for the production of fresh mushrooms (Rabobank, 2016). For the mechanical picked mushrooms the main competition is between the Dutch cultivators (Rabobank, 2016). The margin for Dutch cultivators is low. There is also more competition for Dutch cultivators because of an increase in local-for-local production in Germany and France (Rabobank, 2016) and expert opinion).

Currently, the mushroom sector is investing in upscaling, automation and new cultivation techniques, which could lead to higher production and to a reduction in cost price (abnamro, 2012). Research for possibilities of mechanical picking for the fresh market is already ongoing for many years. However, up until now, it was not successful and investments are needed to optimise it further. It is expected that in the future it will replace (part of) the pickers (expert opinion).

Attention to sustainability and labour will remain a precondition for the success of the mushroom market (abnamro, 2012). There is a lot of attention for fair labour in the cultivation of mushrooms (Rabobank, 2016). The working condition for pickers has recently been discussed in the Netherlands. Working conditions could be improved by narrowing the cultivation beds in the cultivation cells to make the picking easier. However, this will reduce the production per m^2. If this would be obliged for the Netherlands only, it will be fatal for the fresh mushroom production in the Netherlands (expert opinion). In the Netherlands, it is hard to find employees to pick the mushrooms (expert opinion).

Experts of the mushroom market expected that there will be an increased use of alternatives for pesticides. Approval of pesticides for mushrooms will be more difficult in the future, due to planet proof certifications (expert opinion). However, experts stated as well that organic mushroom production in Europe is hardly possible, because then the straw used for the compost should also be from organic cultivation. It is possible to deliver organic mushrooms to the US because the requirements are less strict in the US (expert opinion). In 4-5 years, the mushroom sector wants to be free of pesticides as is stated in the ambition plan plant health mushrooms (expert opinion). Much research is being performed on alternative methods instead of using pesticides, for example using nematodes. When the mushrooms can be claimed free of pesticides, this could also positively influence the price of mushrooms (expert opinion). It is also expected that more preventive hygiene practices will be used in the near future to further decrease the need for pesticides (expert opinion).

Production of fresh white button mushrooms will increase worldwide. In China, investments in production of mushrooms is increasing in which Dutch technologies are used (expert opinion). Due to the consumer trends mentioned previously, the cultivation of other mushrooms, such as truffles, nameco, oyster mushrooms and shiitake is growing in the Netherlands. This is also confirmed for new product introductions with shiitake, chanterelle and portobello, which are grown relatively close-by: about 90% of the products that showed a country of origin are produced in the Netherlands, while a few products came from Germany or Belgium (Innova).

The cultivation of exotic mushrooms is often on sawdust-based substrates (expert opinion). In Asia, the cultivation of exotic mushrooms is popular, with Korea as an important producer of these mushrooms. Instead of cultivation beds, these exotic mushrooms are usually cultivated in flasks (expert opinion).

The Brexit will make it probably more difficult for the Dutch sector to export to the UK, due to additional administration. Therefore, export could reduce (expert opinion). More import from China is expected by the experts of the mushroom supply chain (expert opinion).

Experts mentioned that more preventive hygiene practices, like disinfection agents, will be used in the future, which could influence the food safety. More import from Asia could also affect the food safety due to differences in practices and standards in Asia.

4 Conclusions

This report gives an overview of chemical hazards that may occur in the mushroom supply chain. A literature review was performed and Dutch monitoring data and RASFF data were used to compile a long list that includes all chemical hazards that might occur in mushrooms. The long list consists of the following chemical hazards: heavy metals and other elements, radionuclides, pesticides, persistent organic pollutants, mycotoxins, natural toxins, nicotine, processing contaminants, cleaning and disinfection agents, allergens, perchlorate, colourings and flavour enhancers. Subsequently, an intermediate list was established of substances that were frequently detected to be present and/or found above the legal limits. Unauthorized substances that were found and substances that were indicated to cause human health problems were also included in the intermediate list as well as substances with limited information (knowledge gaps).

The intermediate list included the heavy metals and elements: cadmium, lead, mercury, arsenic, PGEs and aluminium since a few studies showed levels of concern for these compounds in cultivated mushroom species from outside the Netherlands. *Agaricus* (white button mushrooms, chestnut mushrooms and portobellos), which are the main consumed mushrooms in the Netherlands, did not contain high levels of contaminants. The levels of heavy metals and other elements can be clearly higher in wild mushrooms as local levels of heavy metals in the environment may be high. Consequently, the levels in wild mushrooms may exceed levels of human health concern (HBGVs).

Regulated maximum limits for radionuclides were not exceeded in cultivated mushrooms. Dependent on the presence of radionuclides in the environment, wild mushrooms could accumulate high radionuclides levels exceeding regulated MLs. Occasionally, high values were found in wild mushrooms for ^{137}Cs, ^{226}Ra, ^{210}Pb and ^{210}Po.

In the Netherlands, only three pesticides are approved for use in mushroom cultivation. However, MRL exceedances in cultivated mushrooms were found for bifenthrin, carbofuran, carbendazim chlorpyrofos, deltamethrin, fenpropathrin, fipronil, procymidone, tetramehtrin, β-cyfluthrin, β-cypermethrin, λ-cyhalothrin. MRL exceedance of pesticides in wild mushrooms were found for permethrin, propoxur and tetramethrin. These pesticides were all included on the intermediate list. They are currently are all included in the multi-methods used for monitoring of pesticides in the Netherlands.

Some specific mushroom species contain natural toxins, mainly amatoxins, that can be lethal. Therefore, collection of wild mushrooms for consumption can be risky, because toxic mushrooms can be mistaken for edible species. In the literature and RASFF notifications, several incidences with consumption or presence of amatoxins in edible mushrooms were found.

In the past, nicotine levels above the MRL have been found in mushrooms. The cause of the presence of nicotine is still unknown. Disinfection agents (like formaldehyde, trihalomethanes, haloacetic acids, and chlorate) are often used in cultivation and processing of mushrooms. However, data are limited and, therefore, more data are needed on the possible presence of disinfection residues. Therefore, nicotine and disinfection agents were also added to the intermediate list.

All substances on the intermediate list should be evaluated further to determine their possible risk for human health by combining concentrations found and consumption data. Substances with a possible health risk should be included in the short list: substances that should be included in risk based monitoring programs for mushrooms.

Trends that could affect the presence of chemical hazards were also studied. Mushrooms perfectly fit in the current consumer trends of health, sustainability, convenience and plant-based. Consumer trends, like increased use and consumption of mushroom extracts, medicinal and exotic mushrooms could have an influence on the presence of chemical hazards. Cultivation of exotic mushrooms in the Netherlands has recently increased. However, so far, exotic mushrooms are often imported. Increased import from Asia could affect the food safety due to differences in practices and standards in Asia; these import products should be monitored on the compliance with EU standards. Innovations in mushroom processing to increase shelf life, enriched mushrooms, new packaging, and other new processing techniques may also have consequences for the chemical food safety of the products. Alternatives for compost or casing soil are expected to be used in the future; these could contain other chemical hazards that could accumulate in mushrooms. Therefore, compost and casing soil should be checked on chemical hazards. Experts mentioned that more preventive hygiene practices (like disinfection) will be used in mushroom cultivation, which could positively influence the food safety. Overall, it is important to keep track of trends and new developments in the mushroom supply chain.

Acknowledgements

The authors would like to thank the experts who contributed to this study. Experts who participated by filling in the questionnaire or answering the questions related to trends in the mushroom supply chain in an interview are thanked for their input. Marca Schrap, Jacqueline Castenmiller, Linda Kox (NVWA) and Maryvon Noordam and Ine van der Fels-Klerx (RIKILT) are kindly thanked for their input into the research and for critically reading this report.

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Annex 1 English-Dutch list of terms and abbreviations

A1. General terms used

English	Abbreviations	Dutch
(Chemical) substances		(Chemische) stoffen
Acceptable daily intake	ADI	Acceptabele dagelijkse inname
Active ingredient		Werkzame stof
Acute reference dose	ARfD	Acute referentie dosis
Aflatoxin		Aflatoxine
Allergen		Allergeen
Aluminium	Al	
Analytical method		Analyse methode
Animal origin		Dierlijke oorsprong
Animal products		Dierlijke producten
Benchmark dose lower bound	BMDL	
Biocides		Biociden
Bundesinstitut für Risikobewertung	BfR	
Chain analysis		Ketenanalyse
Chemical substances		Chemische stoffen
Components		Componenten
Contaminants		contaminanten
Contamination		verontreiniging
Coplanar polychlorinated biphenyls	Co-PCBs	
Detection limit		Dectectie limiet
Dioxins		Dioxine
Emerging risks		Opkomende gevaren
Endocrine disruptors		Hormoonverstorende soffen
European Food Safety Authority	EFSA	
European Union	EU	Europese Unie
Exposure		blootstelling
Food and Agricultural Organization of the United Nations	FAO	
Food and agriculture organisation (US)	FAO	
Good agricultural practices	GAP	
Hazard analysis		Gevaren analyse
Hazard Analysis and Critical Control Points	HACCP	
Hazards		Gevaren
Health-based guidance value	HBGV	Gezondheidskundige richtwaarde
International Agency for Research on Cancer	IARC	
Joint FAO/WHO Expert Committee on Food Additives	JECFA	
Limit of detection	LOD	
Limito of quantification	LOQ	
Margin of exposure	MOE	
Margin of Exposure	MOE	
Maximum Limit	ML	
Maximum residue level	MRL	
Ministry of Health, Welfare and Sport		Ministerie van VWS
National Institute for Public Health and the Environment	RIVM	Rijksinstituut voor Volksgezondheid en Milieu
Netherlands Food and Consumer Product Safety Authority	NVWA	
No observed adverse effect level	NOAEL	Level waarbij geen schadelijke effecten meer worden waargenomen
Non-compliant		Niet-conform
NVWA department for Risk Assessment and Research	BuRO	Bureau Risicobeoordeling & onderzoek

English	Abbreviations	Dutch
Per- and polyfluoroalkyl subtances	PFAS	Per- en polyfluoralkylverbindingen
Persistent Organic Pollutants	POPs	Persistente organische verontreinigende stoffen
Pesticides		Pesticiden
Plant products		Plantaardige producten
Plant protection products		Gewasbeschermingsmiddelen
Platinum	Pt	
platinum group elements	PGEs	
polychlorinated dibenzofurans	PCDFs	
Polychlorinated dibenzo-p-dioxins	PCDDs	
Polycyclic Aromatic Hydrocarbons	PAHs	Polycyclische aromatische koolwaterstoffen
Processing aid		Technische hulpstof
Processing contaminant		Procescontaminant
Production chain		Productie keten
Provisional tolerable weekly intake	PTWI	
Provisional tolerable daily intake	PTDI	
Rapid Alert System for Food and Feed	RASFF	
Rare earth elements	REEs	
Recommended daily allowance	RDA	aanbevolen dagelijkse hoeveelheid
Reference dose (acute)	RfD	referentie dosis (acuut)
Risk analysis		Risico analyse
Risk based		Risicogebaseerd
Risks		Risico's
Sample/sampling		Monster/bemonstering
Selenium	Se	
substances		Stoffen
tolerable daily intake	TDI	aanvaardbare dagelijkse inname
Tolerable upper intake level	UL	
tolerable weekly intake	TWI	aanvaardbare wekelijkse inname
Unauthorized substances		Niet-toegestane middelen/stoffen
United States environmental protection agency	US EPA	
United States Food and Drug Administration	US FDA	
Veterinary drugs/veterinary medicinal products		Diergeneesmiddelen
Wageningen Food & Biobased Research	WFBR	
World Health Organisation	WHO	Wereld Gezondheidsorganisatie

A2. List of mushrooms mentioned in the report

Genus	English name	Nederlandse naam
Agaricus	Agaric, Agaricus, Agaricus blazei, Agarikusutake, Brazil Mushroom, Brazilian Mushroom, Brazilian Sun-Mushroom, Callampa Agaricus, Champignon Agaric, Champignon Brésilien, Champignon du Brésil, Cogumelo do Sol, Kawariharatake, Himematsutake, Mushroom, Sun Mushroom, cremini, chestnut mushroom, portobello, matsutake	champignon, kastanje champignon, portobello, reuzenchampignon, anijs champignon of akkerchampignon
Agrimonia	no other name found	agrimonie, gewoone
Agrocybe	poplar mushroom, velvet pipoppini	populierenleemhoed
Auricularia	jew’s ear, jelly ear	judasoor
Boletus	porcini, cèpe	eekhoorntjesbrood
Chanterelle	chanterelle	cantharellen
Clitocybe	no other name found	paarse schijnridderzwam
Coprinus	shaggy mane, lawyer’s wig	inktzwam
Cortinarius	cortinar webcap, gypsy mushroom	gordijnzwam
Craterellus	trompette du mort	doodstrompet, hoorn des overvloed
Flammulina	enoki	fluweelpootje
Ganoderma	lingzhi mushroom	
Grifola	hen-of-the-woods, maitake	maitake, eikhaas
Gyromitra	no other name found	
Hericium	monkey’s head, lion’s mane, bear’s head	pruikzwam
Hydnum	hedgehog mushroom	
Hypsizygus	shimeji	beukenzwam
Lactarius	indigo milk cap, candy cap, saffron milk cap	
Lentinula	shiitake	shiitake
Lentinus	shiitake	
Lepista	wood blewit, blewit	
Morchella	morel	morielje
Pholiota	nameko	goudkopje
Pleurotus	oyster mushroom	oesterzwam
Rhizopus	no other name found	
Sparassis	cauliflower mushroom	
Stropharia	roundheads	tuingigant, koningsstropharia, bourgondische paddestoel
Terfezia	no other name found	
Tremella	no other name found	
Tricholoma	no other name found	ridderzwam
Tuber	truffle	truffel
Ustilago	no other name found	
Volvariella	paddy straw mushroom	tropische beurszwam of rijst-stro-paddenstoel

Annex 2 Relevant search terms and scientific databases

Initial searches in Scopus
The following 'basic setup of search terms' will be used:

> *#1: Mushrooms:*
> Exact terms will be defined in this report
> (in title)
> AND
> *#2: Chemical hazards:*
> "Food contamination" OR "Chemical pollutant*" OR "chemical hazard*" OR contamina* OR toxin* OR "toxic substance*" OR "toxic compound*" OR pollutant* OR "agricultural chemical*" OR "chemical compound*" OR "chemical substance*" OR residu*
> (in title, abstract or keywords)
> AND
> #3: Public Health:
> *"Public health" OR "HACCP" OR "Consumer protection" OR Consumer* OR "Food safety" OR "risk assessment*" OR "risk analys*" OR "hazard analys*" OR "Human health*" OR "Health impact" OR "health risk*"*
> (in title, abstract or keywords)
>
> Limited to publications years 2008-2018

First of all, all genus as mentioned in the overview 'ketenklassen' for mushrooms have been used and the available English names were added.

Option 1:
#1 TITLE (Mushroom* OR Agaricus OR Agrocybe OR Auricularia OR Boletus OR Clitocybe OR Coprinus OR Cortinarius OR Craterellus OR Flammulina OR Ganoderma OR Grifola OR Gyromitra OR Hericium OR Hydnum OR Hypsizygus OR Lactarius OR Lentinula OR Lentinus OR Lepista OR Morchella OR Pholiota OR Pleurotus OR Rhizopus OR Sparassis OR Stropharia OR Terfezia OR Tremella OR Tricholoma OR Tuber OR Ustilago OR Volvariella OR Agaric OR "Callampa Agaricus" OR Champignon* OR "Cogumelo do Sol" OR Kawariharatake OR Himematsutake OR cremini* OR portobello* OR "velvet pipoppini" OR "jew's ear*" OR "jelly ear*" OR porcini OR cèpe* OR "shaggy mane*" OR "lawyer's wig*" OR "cortinar webcap*" OR enoki OR lingzhi OR "hen-of-the-woods" OR maitake* OR "monkey's head*" OR "lion's mane*" OR "bear's head*" OR "hedgehog mushroom*" OR shimeji OR "indigo milk cap*" OR "candy cap*" OR shiitake* OR "wood blewit*" OR morel* OR nameko OR "oyster mushroom*" OR "cauliflower mushroom*" OR roundhead* OR truffle* OR "paddy straw mushroom*" OR Chanterelle*)

AND #2 chemical hazards AND #3 publish health as in basic setup, limited to publication years 2008-2018

Option 2:
Idem as option 1 but in #1 Fusarium was removed. Fusarium is a microfungus, which can produce microproteins that can be used for Quorn products. Quorn claims that their product are mushroom-based, however this is not correct, fusarium is not a mushroom. Furthermore, fusarium is a fungus that can affect cereals, causing different diseases in the plants.

Option 3:
idem as option 2, but all mushrooms terms were also searched in TITLE-ABS-KEY

Option 4:
Only # 1 and #2, without public health terms.

The first 50 hits were screened for relevant papers based on title and if needed also based on abstract. Only four papers were selected as relevant papers. Many of the found papers were about growth and yield optimisation of mushrooms, beneficial health effect of compounds as present in mushrooms(in vitro) and papers about analytical methods. This topics are not relevant for our study.

Afterwards it was checked and found that these four relevant papers were also found by the search in option 3. The addition of the "public health" terms, makes our search more specific, and relevant papers are found.

Scopus searches overview

Search option	Hits	remark	
Option 1	348	Mushroom in TITLE Other term in TITLE-ABS-KEY	
Option 2	154	Fusarium is no mushroom, therefore removed	Relevant hits of option 4 are also found with this search option
Option 3	471	All terms in TITLE-ABS-KEY	
Option 4	1775	Only #1 and #2, without public health terms	4 relevant hits in first 50 hits

Other databases
Same search as option 2 for Scopus have been used in 3 other databases, hits and duplicates with Scopus are presented in table below. Hits were screened for possible relevant new papers not yet found in Scopus, numbers are indicated in the table.

	Search option	Hits	Duplicates with Scopus	Possible relevant new papers (excl duplicates with Scopus)
CAB Abstracts	2	86	20	3
Web of Science	2	88	25	30
AGRIS	2	20	-	Not assessed

Based on these numbers, Web of Science is selected as the most relevant database next to Scopus.

Other search terms for "mushrooms" in Scopus
option 5 main consumed mushrooms:
#1 TITLE(Mushroom* OR Agaricus OR Lentinula OR Lentinus OR Pleurotus OR Volvariella OR Chanterelle* OR champignon* OR shiitake* OR "oyster mushroom" OR "paddy straw mushroom" OR agaric OR portobello OR cermini)
AND #2 chemical hazards AND #3 publish health as in basic setup, limited to publication years 2008-2018

option 6 new list based on EFSA:
#1 TITLE (Mushroom OR Blewit* OR boletus OR chanterelle* OR "Gypsy mushroom*" OR "hedgehog mushroom*" OR "lion's mane mushroom*" OR matsutake* OR morel* OR "oyster mushroom*" OR "saffron milk cap*" OR "trompette du mort*" OR truffle* OR enoki OR "yeast extract*")
AND #2 chemical hazards AND #3 publish health as in basic setup, limited to publication years 2008-2018

option 7 only "mushroom*"
#1 TITLE (Mushroom*)
AND #2 chemical hazards AND #3 publish health as in basic setup, limited to publication years 2008-2018

Scopus

Search option	Hits	remark
option 5	113	Main consumed mushrooms
option 6	113	New list based on EFSA
option 7	101	Only "mushroom*"

Based on an interview with a mushroom expert (WUR), the main imported and exported mushrooms in the Netherlands were identified and if needed added to the initial search. A comparison was also made with the 'ketenklassen indeling" based on EFSA, some extra English names were added.

An overview of Latin names, English names and Dutch names of all identified mushrooms can be found in the appendix

option 8 All identified relevant names for mushrooms:
#1 TITLE(Mushroom* OR Agaricus OR Agrimonia OR Agrocybe OR Auricularia OR Boletus OR Clitocybe OR Coprinus OR Cortinarius OR Craterellus OR Flammulina OR Ganoderma OR Grifola OR Gyromitra OR Hericium OR Hydnum OR Hypsizygus OR Lactarius OR Lentinula OR Lentinus OR Lepista OR Morchella OR Pholiota OR Pleurotus OR Rhizopus OR Sparassis OR Stropharia OR Terfezia OR Tremella OR Tricholoma OR Tuber OR Ustilago OR Volvariella OR Agaric OR Agarikusutake OR "Callampa Agaricus" OR Champignon* OR "Cogumelo do Sol" OR Kawariharatake OR Himematsutake OR cremini* OR portobello* OR Matsutake OR "velvet pipoppini" OR "jew's ear*" OR "jelly ear*" OR porcini OR cèpe* OR "shaggy mane*" OR "lawyer's wig*" OR "cortinar webcap*" OR "trompette du mort" OR enoki OR lingzhi OR "hen-of-the-woods" OR maitake* OR "monkey's head*" OR "lion's mane*" OR "bear's head*" OR "hedgehog mushroom*" OR shimeji OR "indigo milk cap*" OR "candy cap*" OR "saffron milk cap" OR shiitake* OR "wood blewit*" OR morel* OR nameko OR "oyster mushroom*" OR "cauliflower mushroom*" OR roundhead* OR truffle* OR "paddy straw mushroom*" OR chanterelle*)

AND #2 chemical hazards AND #3 publish health as in basic setup, in title, abstract or keywords, limited to publication years 2008-2018

Scopus	option 8	154		
Web of Science	option 8	88	25	
Total				217

Conclusion
Scopus and Web of Science were identified as the most relevant scientific databases. Search options including public health search terms (#3), resulted in relatively most relevant hits for our study. Initial search terms for mushrooms covered al lot of hits. Searches for only the term "mushroom*" or most consumed mushrooms resulted in a relevant number of hits, however some extra relevant papers will be found by using all identified relevant names for mushrooms. Therefore, all search terms as performed in option 8 will be included to find an optimal number of relevant hits.

Annex 3 Relevant websites

Advanced search in google was used to search on relevant websites. During the interview with the WUR expert, the main mushroom producing countries were identified. 1. China 2. United States 3.Poland/The Netherlands. Therefore websites of US authorities seemed to be relevant. China and Poland were not included, since these websites were not available in English. Identification of nicotine in mushrooms by the Belgium authority was also mentioned during the interview. Germany and France were also mentioned as important export countries. Therefore, also the Belgium, German, French and Dutch authorities were included in the initial searches.

The following initial searches via google on these specific websites were performed:

http://www.efsa.europa.eu/	
Search terms: Mushroom AND safety	106 hits
Search term: mushroom AND (safety OR hazard OR risk)	276 hits
Limited to 2008-2018:	32 hits
Search term: mushroom AND ("food safety" OR hazard OR risk):	164 hits
https://www.fda.gov/	
Search term: mushroom AND ("food safety" OR hazard OR risk)	348 hits
Limited to 2008-2018:	226 hits
http://www.who.int/	
Search term: mushroom AND ("food safety" OR hazard OR risk)	80 hits
Very general hits	
http://www.fao.org	
mushroom* AND ("food safety" OR hazard OR risk)	386 hits
Limited to 2008-2018:	107 hits
http://www.afsca.be	
mushroom	118 hits
champignon AND voedselveiligheid	75 hits
mushroom* AND ("food safety" OR hazard OR risk)	8 hits
many general reports and general monitoring, no specific reports on mushrooms for all search strings	
www.nvwa.nl	
mushroom	20 hits
champignon AND voedselveiligheid	6 hits
https://www.bfr.bund.de	
mushroom* AND ("food safety" OR hazard OR risk)	56 hits
some relevant hits specific for mushroom or dried mushrooms	
www.anses.fr	
mushroom* AND ("food safety" OR hazard OR risk)	31 hits
many hits in French, many hits with warning for wild mushrooms	

Conclusion

Relevant selected websites:
http://www.efsa.europa.eu/
https://www.fda.gov/
http://www.fao.org
https://www.bfr.bund.de

Annex 4 Questionnaire used to obtain information on trends in the mushroom supply chain (in Dutch)

Vragenlijst toekomst en trends –Paddenstoelenketen

1. Welke veranderingen en ontwikkelingen verwacht u de komende 10 jaar in de padenstoelensector?
   Click or tap here to enter text.
   a. Verwacht u veranderingen door de Brexit?
      Click or tap here to enter text.
   b. Verwacht u veranderingen in import?
      Click or tap here to enter text.
   c. Verwacht u specifieke ontwikkelingen voor bepaalde soorten? (wilde of geweekte paddenstoelen)
      Click or tap here to enter text.

2. Welke trends verwacht u in de paddenstoelenteelt? (bijv. andere oogstmethoden, andere bestrijdingsmethoden)
   Click or tap here to enter text.

3. Welke trends verwacht u in de productie van compost en dekaarde?
   Click or tap here to enter text.

4. Welke trends verwacht u de verwerkende industrie? (bijv. nieuwe producten, andere technologieën)
   Click or tap here to enter text.

5. Zijn er bepaalde consumententrends die relevant zijn voor de paddenstoelensector? (bijv. meer vers, meer convenience food, andere soorten)
   Click or tap here to enter text.

6. Wat verwacht u van de superfoodtrend in de komende 10 jaar?
   Click or tap here to enter text.

7. Welke microbiologische gevaren vindt u het belangrijkst in paddenstoelen en verwerkte producten van paddenstoelen? (bevroren, gedroogd, conserven etc.)
   Click or tap here to enter text.
   a. Voor welke soorten en waarom?
      Click or tap here to enter text.

8. Welke chemische gevaren vindt u het belangrijkst in paddenstoelen en verwerkte producten van paddenstoelen? (bevroren, gedroogd, conserven etc.)
   Click or tap here to enter text.
   a. Voor welke soorten en waarom?
      Click or tap here to enter text.

Annex 5 Comparison of relevance evaluation of scientific papers

Nr	Reference	Scientist 1	Scientist 2	Remarks
1	(Akram and Kwon, 2010)	Not relevant	Not Relevant: use of irradiation to increase shelf-life	
2	(Alonso et al., 2013)	Relevant	Relevant: data on Cs in Spanish wild mushrooms	
3	(Aloupi et al., 2012)	Relevant	Relevant: heavy metals levels in wild mushrooms	
4	(Andaluri et al., 2012)	Not relevant	Maybe Relevant: hormone levels in mushroom compost	Papers was also checked for relevant information.
5	(Drewnowska et al., 2017)	Relevant	Relevant: heavy metal concentrations in wild mushrooms and the effect of processing on concentrations	
6	(Falandysz et al., 2017a)	Relevant	Relevant: heavy metal concentrations in wild mushrooms from Poland	
7	(Fernandes et al., 2012)	Not relevant	Not relevant: see Akram et al.	
8	(Garcia-Delgado et al., 2013)	Not relevant	Not relevant: method development	
9	(Huang et al., 2017)	Relevant	Maybe relevant: Chinese intake assessment	
10	(Karadeniz and Yaprak, 2010)	Relevant	Maybe relevant: radionuclide levels in Turkish mushrooms	
11	(Mansour et al., 2009)	Not relevant	Not relevant: potatoes	
12	(Melgar et al., 2016)	Relevant	Relevant: Cd levels in wild and cultured mushrooms	
13	(Muttucumaru et al., 2014)	Not relevant	Not relevant: potatoes and asparagus	
14	(Petrović et al., 2013)	Relevant	Maybe relevant: Heavy metal levels in wild mushrooms in polluted areas	
15	(Schiavo et al., 2015)	Not relevant	Not relevant: physical hazards	
16	(Türkmen and Budur, 2018)	Relevant	Maybe relevant: heavy metal concentrations in Turkish wild mushrooms	
17	(Zhao et al., 2018)	Relevant	Not relevant: method development	Pesticides were measured in cultivated mushrooms, these data were included in the report.
18	(Yang et al., 2015)	Relevant	Maybe relevant: heavy metal concentrations in Chinese wild mushrooms	
19	(Prand-Stritzko and Steinhauser, 2018)	Relevant	Relevant: radionuclide levels in Japanese mushrooms after Fukushima	
20	(Mleczek et al., 2016a)	Relevant	Relevant: heavy metal levels in mushrooms	
21	(Krasinska and Falandysz, 2016)	Relevant	Relevant: mercury levels in mushrooms	
22	(Gałgowska et al., 2012)	Relevant	Relevant: pesticide levels in Polish wild mushrooms	

Annex 6 Results Google searches on relevant websites

Table A1 *Number of hits found with google searches on relevant websites*

Searches	EFSA[a]	FAO[b]	BfR[c]	FDA[d]
1. mushroom AND “food safety”	222	1860	**54**	**183**
2008-2018	**38**	236		
only PDF		**216**		
2. mushroom AND (contaminant OR residue)	>200	1130	**96**	**84**
2008-2018	**41**	**134**		
3. mushroom AND “risk assessment”	**131**	1130	**86**	**41**
2008-2018		**151**		
total hits	**210**	**501**	**236**	**308**
total relevant hits	**11**	**5**	**5**	**4**

[a] http://www.efsa.europa.eu,

[b] http://www.fao.org,

[c] https://www.fda.gov,

[d] https://www.bfr.bund.de

Annex 7 Results additional searches on Scopus

- (“flavour enhancer*” OR “monosodium glutamate” OR colour*) AND mushroom* AND (“food safety” OR hazard* OR risk*) resulted in 7 hits, no relevant papers were found about hazards in mushrooms related to flavour enhancers or colourings.
- (mushroom* AND mycotoxin* AND (“food safety” OR hazard* OR risk*)) resulted in 22 hits, no additional relevant papers were found about mycotoxin hazards in edible mushrooms.
- (mushroom* AND (“Persistent organic pollutants” OR PAH OR PCB OR dioxin OR PFA OR BFR)) resulted in 95 hits, one additional relevant paper was found about hazards related to persistent organic pollutants in edible mushrooms.
- (mushroom* AND nicotine) resulted in 53 hits, one additional relevant paper was found about hazards related to nicotine in edible mushrooms.
- (mushroom* and allerg*) for 2008-2018 resulted in 175 hits, 3 additional relevant papers were found about allergens in edible mushrooms.
- (mushroom* AND (“processing contaminants” OR furan OR acrylamide OR 3-mcpd)) for 2008-2018, resulted in 67 hits, no additional relevant papers were found.
- (mushroom* AND (cleaning OR disinfect*) for 2008-2018, resulted in 84 hits, 3 additional relevant papers were found about cleaning and disinfection agents used for edible mushrooms.

Wageningen Food Safety Research
P.O. Box 230
6700 AE Wageningen
The Netherlands
T +31 (0)317 48 02 56
www.wur.eu/food-safety-research

WFSR report 2019.006

To explore the potential of nature to improve the quality of life

Wageningen Food Safety Research
P.O. Box 230
6700 AE Wageningen
The Netherlands
T +31 (0)317 48 02 56
www.wur.eu/food-safety-research

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