Literature study on the chemical hazards in bulbs, tubers, stem and root vegetables

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Summary

This report describes the results of a literature study performed for NVWA-BuRO in order to identify chemical hazards in bulbs, tubers, stem and root vegetables that are produced and/or consumed in the Netherlands. For the sake of convenience, these vegetables are referred to as underground vegetables in the remainder of this report. Potatoes were not included in this report since these were evaluated previously (Nijkamp et al., 2017). Search terms were predefined and used to obtain relevant scientific papers from the databases Scopus and Web of Science. Furthermore, the advanced search feature of Google was used to obtain relevant reports from the websites of four organizations (BfR, EFSA, FAO and FAVV). In case the number of hits for a certain chemical hazard group was limited or only experimental studies were found, an additional more specific literature search was performed for the particular hazard group. Based on title, keywords and abstract, the relevancy of the papers for the aims of our study was evaluated. Papers that were judged relevant were read in full and information from these papers on, amongst others, vegetables studied, chemical hazards included, country of origin, and reported concentrations, were extracted. This information was then stored in an Excel file.

Long list of chemical hazards in underground vegetables
The literature search in Scopus and Web of Science resulted in a total of 237 scientific papers. Of these, 97 were judged to be relevant. Additionally, 21 relevant hits were obtained using the Google search and 8 papers were included after the additional literature search. Most information was obtained for carrot, cassava and radish. Based on the information obtained, a long list of chemical hazards could be identified; this list contains chemical hazards that might be present in underground vegetables. The long list for underground vegetables includes heavy metals and essential elements, perfluorinated compounds, polycyclic aromatic hydrocarbons (PAHs), nitrate, pharmaceutical compounds, radionuclides, plant protection products, mycotoxins, plant toxins, processing contaminants, cleaning agents and disinfectants, and other chemical hazards such as phthalates, microcystin and nanoparticles.

Intermediate list of chemical hazards in underground vegetables
Those chemical hazards that were frequently found in underground vegetables and/or reported at concentrations exceeding the (EU) legal limits and/or resulting in an exceedance of health-based guidance values (HBGVs) were included on the so-called intermediate list. The heavy metals, arsenic (As), cadmium (Cd) and lead (Pb) were added on the list since multiple papers reported their occurrence in underground vegetables (in case of As), or levels were found above the EU Maximum Levels (MLs) (in case of Cd and Pb). PAHs were added on the intermediate list since a literature review indicated that levels > 5 µg/kg may be found in underground vegetables when grown in urban or industrial areas. Radish and beetroot have a high contribution (>50%) to the Acceptable Daily Intake for nitrate; therefore, this substance was also added to the intermediate list. In total, 15 pesticides were added to the intermediate list since these were either frequently found or exceeded EU Maximum Residue Limits (MRLs), primarily in leek and carrot. The mycotoxins, aflatoxin B1 (EU ML exceedance in ginger) and fumonisins (high concentrations up to 3940 µg/kg found in onions) were included on the intermediate list. Hydrocyanic acid was added since concentrations above the ML of the Food Standards Australia New Zealand were found in cassava and consumption of cassava crisps was shown to result in an exceedance of the Acute Reference Dose. Perchlorate levels above the EU MRL were found in underground vegetables. Therefore, this substance was also included on the intermediate list. Consumption of underground vegetables was shown to contribute to 13% of the dietary phthalate intake. As such, phthalates were included on the list. For some chemical hazards, the information found was too limited to determine whether they should be in- or excluded on the intermediate list. This was the case for the element aluminium, the pharmaceuticals lamotrigine and 10,11-epoxycarbamazepine, the mycotoxin moniliformin and the surfactants nonylphenol, alkylsulfates and linear alkylbenzene sulfonates. These substances were all identified as knowledge gap. For these chemical hazards and for those that were included on the intermediate list, toxicological information was collected based on EFSA and RIVM

reports as well as HBGVs. This information can be used as input to come to a short list of chemical hazards that should be included in the national monitoring program.

Evaluation of trends

Previously, trends for vegetables in general have been evaluated (Banach et al., 2019). This was supplemented with a specific Google search for underground vegetables. The information obtained showed that a relevant trend with respect to food safety is the interest in the use of treated wastewater and sludge in open field cultivation. Although not applied (yet) in the Netherlands, these practices are used elsewhere and, as a result, imported products may contain levels of chemical hazards present in wastewater, such as residues of pharmaceuticals. Another important trend is the expected increased temperatures in summer, which may lead to increased levels of cyanotoxins in irrigation water that eventually may end up in vegetables produced in open fields. Furthermore, vegetables such as beetroot are increasingly used as replacement of carbohydrate-rich food, which may result into an increased intake of chemical hazards from consumption of underground vegetables.

Samenvatting

Dit rapport geeft de resultaten van een literatuurstudie die voor NVWA-BuRO is uitgevoerd om de chemische gevaren in bol-, wortel- en knolgewassen en in stengelgroenten in kaart te brengen die in Nederland geproduceerd en/of geconsumeerd worden. Voor het gemak worden deze groenten in de rest van het rapport aangeduid met de term 'ondergrondse groenten'. Aardappels waren geen onderdeel van deze studie, aangezien de chemische gevaren in aardappel beschreven zijn in een eerder rapport (Nijkamp et al., 2017). Scopus en Web Of Science werden gebruikt om met vooraf vastgestelde zoektermen artikelen te zoeken gerelateerd aan het onderwerp. Verder werd de geavanceerde zoekoptie in Google gebruikt om relevante rapporten te zoeken op de websites van 4 organisaties (BfR, EFSA, FAO en FAVV). Indien het aantal hits voor een bepaalde gevarengroep beperkt was of indien alleen experimentele studies werden gevonden, werd nog een additionele literatuurstudie uitgevoerd. Op basis van titel, keywords en abstract werd bepaald of een artikel relevant was. Relevante artikelen werden volledig gelezen en informatie uit deze artikelen (zoals de onderzochte groentes, de chemische gevaren, land van herkomst, gevonden concentraties) werden in een Exceltabel samengevat die apart bij dit rapport werd opgeleverd aan NVWA-BuRO.

Long list van chemische gevaren in ondergrondse groenten
In totaal werden 237 wetenschappelijke artikelen verkregen met Scopus en Web of Science. Hiervan waren 97 artikelen relevant. Verder werden in de Google search nog 21 relevante artikelen gevonden en 8 artikelen na een additionele literatuurstudie. De meeste informatie werd verkregen voor wortel, cassave en radijs. Op basis van de informatie uit de relevante artikelen werd een zogenaamde 'long list' van chemische gevaren opgesteld. Deze lijst bevat chemische gevaren die mogelijk kunnen voorkomen in ondergrondse groenten. De long list bevat zware metalen en essentiële elementen, perfluorverbindingen, polyaromatische koolwaterstoffen (PAK's), nitraat, geneesmiddelen, radionucliden, gewasbeschermingsmiddelen, mycotoxinen, planttoxinen, procescontaminanten, reinigings- en desinfectiemiddelen en overige chemische gevaren zoals ftalaten, microcystine en nanodeeltjes.

Intermediate list van chemische gevaren in ondergrondse groenten
Chemische gevaren die regelmatig gevonden werden in ondergrondse groenten of in concentraties boven de (EU) wettelijke limieten of die resulteerden in een overschrijding van de gezondheidskundige richtwaarden (HBGV's) werden op de zogenaamde 'intermediate list' geplaatst. De zware metalen arseen (As), cadmium (Cd) en lood (Pb) werden op deze lijst gezet, aangezien meerdere artikelen aangeven dat ze gevonden werden in ondergrondse groenten (As) of er concentraties boven de EU Maximale Limieten (ML's) waren aangetroffen (Cd, Pb). PAK's werden toegevoegd, aangezien een literatuuroverzicht aangaf dat concentraties > 5 µg/kg werden gevonden in ondergrondse groenten indien deze verbouwd waren in stedelijke of industriële gebieden. Radijs en rode biet dragen voor een belangrijk deel (> 50%) bij aan de aanvaardbare dagelijkse inname (ADI) van nitraat; deze stof werd daarom ook toegevoegd aan de intermediate list. In totaal werden 15 pesticiden op de intermediate list gezet, aangezien deze ofwel regelmatig gevonden werden, of de EU maximumwaarde voor residuen (MRL's) werden overschreden, voornamelijk in wortel en prei. De mycotoxinen aflatoxine B1 (EU ML-overschrijding in gember) en fumonisinen (hoge concentraties tot 3940 µg/kg gevonden in ui) werden op de lijst gezet. Blauwzuur (HCN) werd toegevoegd, aangezien concentraties boven de ML van de voedselveiligheidsautoriteit van Australië en Nieuw-Zeeland (FSANZ) werden aangetroffen in cassave en consumptie van cassavechips leidde tot een overschrijding van de acute referentiedosis (ARfD). Perchloraat werd aangetroffen in concentraties boven de EU MRL in ondergronds groenten. Deze stof werd daarom ook opgenomen op de intermediate list. Consumptie van ondergrondse groenten droeg voor een belangrijk deel (13%) bij aan de inname van ftalaten. Daarom werd deze stofgroep ook op de lijst gezet. Voor sommige chemische gevaren was de informatie te beperkt om te bepalen of de stoffen op de intermediate list geplaatst moesten worden. Dit was het geval voor het element aluminium, de geneesmiddelen lamotrigine en 10,11-epoxycarbamazepine, het mycotoxine moniliformine en de oppervlakte-actieve stoffen nonylfenol, alkylsulfaten en lineair

alkylbenzeensulfonaten. Al deze stoffen werden aangemerkt als kennisleemte. Voor deze stoffen en voor de stoffen op de intermediate list werd toxicologische informatie weergegeven in het rapport, gebaseerd op EFSA- en RIVM-rapporten, evenals gezondheidskundige richtwaarden (HBGV's). Deze informatie kan gebruikt worden om tot een short list van chemische gevaren te komen, die opgenomen zouden moeten worden in het nationale monitoringsprogramma.

Evaluatie van trends

In een eerder rapport (Banach et al., 2019) werden trends voor groenten in het algemeen weergegeven. Dit is aangevuld met specifieke informatie over ondergrondse groenten via een Google zoekopdracht. De verkregen informatie liet zien dat een belangrijke trend met betrekking tot voedselveiligheid de interesse is in het gebruik van behandeld afvalwater en slib bij vollegrondsteelt. Alhoewel (nog) niet toegepast in Nederland, worden beide al wel in andere landen toegepast en geïmporteerde producten kunnen als gevolg hiervan chemische gevaren bevatten die in het afvalwater aanwezig waren, zoals residuen van geneesmiddelen. Een andere relevante trend zijn de toegenomen temperaturen in de zomer die kunnen leiden tot een toename in concentraties cyanotoxinen in het irrigatiewater. Uiteindelijk kunnen deze in de gewassen terechtkomen bij vollegrondsteelt. Een andere trend is de vervanging van koolhydraatrijke producten met groenten zoals rode biet. Als gevolg hiervan kan de inname aan chemische gevaren aanwezig in ondergrondse groente toenemen.

1 Introduction

Protecting human and animal health is the overarching goal of The Netherlands Food and Consumer Product Safety Authority (NVWA). Monitoring of possible presence of potential hazards for human and animal health in food and consumer products is key to achieve this goal. Nevertheless, due to limited resources, it is not possible to check all the food and feed products available on the Dutch market. For this reason, prioritisation of monitoring activities by the NVWA is a necessity. For this purpose, NVWA-BuRO performs risk assessments to identify the most relevant hazards in the food and feed supply chain. Both the probability of a hazard occurring in the product and the severity of this hazard (effect on human health) are taken into account in a risk-based approach. Previously, the dairy, feed, egg, poultry and red meat chain have been studied to obtain information on both the prevalence and severity of chemical hazards. Currently, the fruit and vegetables chain is being studied. Due to the diversity and the magnitude of this food chain, this category is divided in the following sub-categories:

1. Fruits
2. Nuts, cereals, and seeds
3. Mushrooms
4. Leafy vegetables
5. Fruiting vegetables
6. Bulb, root, stem and tuber vegetables
7. Other vegetables

The current study focuses on sub-chain 6, the bulb, root, stem and tuber vegetables. In order to increase the readability, the remainder of this report uses the term ‘underground vegetables’ instead of bulb, tuber, stem and root vegetables. The exact vegetables included in this study are indicated in Annex 3.

The aim of this study was to identify possible chemical hazards in underground vegetables available on the Dutch market. The information, given in this report, can be used as input for a risk assessment. In order to guide the Dutch reader of this report, the names of the vegetables used in this report have been translated in Annex 2. Furthermore, Annex 1 gives a list of abbreviations used.

The report gives an overview of the uptake and occurrence of chemical hazards in underground vegetables as obtained in a literature review (section 3.2). Chemical hazards that may occur in these vegetables were placed on the so-called long list (section 3.3). In case the literature review indicated that chemical hazards were frequently found, exceeded the (EU) legal limits or were reported to result in an exceedance of health-based guidance values (HBGVs), these hazards were included on the so-called intermediate list (section 3.4). For the latter hazards, toxicological information was provided (section 3.5). Finally, trends and developments within the supply chain of underground vegetables were evaluated and their possible effect on the occurrence of chemical hazards in these vegetables (section 3.6).

2 Methods

2.1 Project description and demarcation

For the purpose of identifying chemical hazards that are possibly present in underground vegetables, a literature study was performed. The obtained hits were screened for their relevancy as described in 2.3.1. Relevant papers were read in full and information extracted in an Excel file that was provided to the NVWA as complementary document.

The focus of this study was the 'underground vegetables' or in other words the bulb, root, stem and tuber vegetables. Product commodities included in these vegetable groups were based on the European Food Safety Authority (EFSA) classification and the categorization used by the NVWA. Further details can be found in 2.3.1. The following vegetables were excluded from the current study: potatoes, since these have been subject to a previous evaluation (Nijkamp et al., 2017), celery, since this vegetable was included in the report on leafy vegetables (Banach et al., 2019) and sugar beet since this vegetable is not eaten as such but used as industrial crop to produce sugar.

The study focused on raw vegetables meaning that processed vegetables such as canned vegetables and salads were not evaluated. The effect of processing was thus not specifically included in the literature search. Nevertheless, in case the literature review revealed information on the effect of processing on the presence of chemical hazards, this information was included in the report.

2.2 Eurostat imports

In order to prioritise references in hazard groups that retrieved many hits during the literature screening (see section 2.3.1, stage 4), Eurostat import data for the Netherlands for 2017 was used. This selection criterion was applied to papers containing occurrence data. The information on the uptake of chemical compounds by underground vegetables were not prone to the selection criteria based on the import data. Several harmonised system (HS) codes were used to obtain all import data for bulb, root, stem and tuber vegetables. The data was extracted by the NVWA-BuRO in August 2019 for the following food groups:

1. Fresh or chilled onions and shallots (HS Code:70310);
2. Fresh or chilled carrots and turnips (HS Code: 70610);
3. Ginger, neither crushed nor ground (HS Code: 91011);
4. Garlic, fresh or chilled (HS Code:70320);
5. Fresh or chilled salad beetroot, salsify, celeriac, radishes and similar edible roots (HS Code:70690);
6. Fresh or chilled asparagus (HS Code: 70920);
7. Dried onions, whole, cut, sliced, broken or in powder, but not further prepared (HS Code: 71220);
8. Fresh, chilled, frozen or dried roots and tubers of manioc 'cassava', whether or not sliced or in the form of pellets (HS Code: 71410);
9. Leeks and other alliaceous vegetables, fresh or chilled (excl. Onions, shallots and garlic) (HS Code: 70390);
10. Yams 'dioscorea spp.', fresh, chilled, frozen or dried, whether or not sliced or in the form of pellets (HS Code: 71430);
11. Taro 'colocasia spp.', fresh, chilled, frozen or dried, whether or not sliced or in the form of pellets (HS Code: 71440);
12. Arrowroot, salep, Jerusalem artichokes and similar roots and tubers with high starch or inulin content (HS Code: 71490);
13. Yautia 'xanthosoma spp.', fresh, chilled, frozen or dried, whether or not sliced or in the form of pellets (HS Code: 71450).

2.3 Literature study

2.3.1 Scientific literature

The NVWA Chain Classes for Fruits and Vegetables (Ketenklassen GF) as provided to WFSR on 4 September 2018 was used as a basis for the product classification supplemented with the EFSA categories coming from the 2013 report on foods of non-animal origin (EFSA, 2013). The details on the results and choices made for the final classification of vegetables in the underground vegetables group (search terms in #1) are indicated in Annex 4. Furthermore, Annex 4 provides more detailed information on the search terms chosen for chemical hazards (#2), human health (#3) and the exclusion terms used (#4).

1 (product commodity) in Title:
asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*"

AND
#2 (chemical hazards) in Title, abstract, 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 (human health) in Title, abstract, 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*"

AND NOT
#4 (exclusion terms) in Title:
pathogen* OR *streptococcus* OR *listeria* OR **virus** OR *bacillus* OR *salmonella* OR *clostridium* OR *staphylococcus* OR *outbreak* OR "foodborne disease*" OR fung* OR *campylobacter* OR *"Escherichia coli"* OR *"E. coli"* OR model* OR analytic* OR microbio* OR bacteri* OR virol* Or nutri* OR Sweden

Limited to publication years 2009 – 2019

The literature search in Scopus and Web of Science was conducted on the 21st of February 2019.

All hits from Scopus and Web of Sciences were included in an Endnote file. First, the duplicate references were removed. Subsequently, the following steps were applied to extract relevant articles.
1. Relevance of the publication was determined based on the title, abstract and keywords. Papers were then grouped in: relevant, maybe relevant and not relevant in Endnote. Selection of relevant papers was checked by another scientist for a part of the publications.
2. The papers that were evaluated in step 1 as relevant, were read – full text.
3. Relevant papers in step 2 were summarised in an Excel table. Possible chemical hazards, region and country where these hazards were found, reported concentrations, the type and size of the study and the main message of the publications were noted.

2.3.2 Google search

To further support the literature search on possible chemical hazards in underground vegetables, searches were performed using the advanced search feature in Google. In total, four websites from research or food safety institutes were selected for information on chemical hazards in the vegetables under investigation. EFSA and FAO were chosen as relevant institutes related to food safety and vegetables. BfR and FAVV were additionally selected, since the import data showed that most of the vegetables falling in scope of this research were imported from Germany and Belgium. Further details on the selection of the following four websites are described in Annex 5.

The four websites used:
1. European Food Safety Authority (EFSA) (http://www.efsa.europa.eu);
2. Federal Agency for the Safety of the Food Chain (FAVV) (http://www.afsca.be);
3. German Federal Institute for Risk Assessment (BfR) (https://www.bfr.bund.de); and
4. Food and Agricultural Organization (FAO) (http://www.fao.org/).

Since the Google advanced search does not allow for an extensive list of search strings, the approach using separate search terms for individual underground vegetables as done for Scopus and WoS (section 2.3.1) could not be followed. The following three search strings were performed on these four websites:
1. Bulb, root, stem, tuber vegetables AND "food safety"
2. Bulb, root, stem, tuber vegetables AND (contaminant OR residue)
3. Bulb, root, stem, tuber vegetables AND "risk assessment"

When an individual search resulted in more than 200 hits, the last 10 years were selected (2009-2019). If this still resulted in more than 200 hits, only the file type ‘pdf’ was selected.

First, all retrieved hits were screened to check if they included information on a chemical hazard (e.g., not microbiological or physical hazards) in an underground vegetable. Second, relevant hits were read, and the information on the hazards in underground vegetables was extracted in the Excel file supplemented to this report. References containing valuable information, e.g. concentrations of As in radish, were included in this report. If references contained solely general statements, like: ‘many heavy metals are detected in radish’, they were not included. Despite complying with the previously mentioned prerequisites, references could still be excluded if there were too many references for the same chemical hazard, such as for the heavy metals. At this point, the data from Eurostat imports as provided by NVWA-BuRO was used to select information relevant to include in this report.

2.3.3 Additional searches

For some hazard groups, the obtained information via literature and Google search was limited (only few or no papers). Furthermore, for some hazard groups only experimental studies were found. In both cases, an additional literature search was performed in Scopus analogous to 2.3.1 by replacing search terms #2 with the following hazards:
- Nitrate;
- Persistent organic pollutants (POP), Perfluoroalkyl compounds, dioxins, PCBs;
- Processing aids & additives;
- Radionuclides;
- Pharmaceuticals;
- Plant toxins (pyrrolizidine alkaloids, tropane alkaloids).

More detailed information on the search terms for the additional searches is given in Annex 6.

2.4 Prioritisation

The results of the literature study give an indication of the chemical hazards that may occur in underground vegetables, which were subsequently included in the so-called long list of possible chemical hazards (see section 3.3). An intermediate list of chemical hazards was established including those hazards that were frequently mentioned in the literature to be present in underground vegetables and/or which exceeded (EU) legal limits. Furthermore, chemical hazards for which human health problems were reported since their presence resulted in an exceedance of HBGVs or when underground vegetables were indicated as the main contributor to a substance's HBGV were also included on the intermediate list.

In case experimental studies indicated a possible human health risk for certain chemical hazards, but occurrence data on their presence in underground vegetables on the market were lacking, the chemical hazards were identified as knowledge gaps. For the substances on the intermediate list and for the identified knowledge gaps, EFSA opinions and RIVM reports were consulted to establish information on the toxicity of the hazards. This information can be used by NVWA-BuRO to come to a short list of chemical hazards that may impact human health.

2.5 Evaluation of trends

In a previous report, the trends in the coming five years (2020-2024) were described for vegetables in general (Banach et al., 2019). The outcome is summarised in this report (section 3.6). Additionally, a Google search was performed to find information on future trends specifically related to underground vegetables. Furthermore, Wageningen Food & Biobased Research (WFBR) consulted the Innova database specifically for underground vegetables. Innova Market Insights collects all new product introductions, collecting all information available on the package into the Innova Database (www.innovamarketinsights.com). Information about the product that is not mentioned on the package is consequently not in the database, nor is registered how long the product is, was, or has been available on the market. The overview the database provides shows the trend in products in the past years. In the database, products can be sorted based on the type of ingredients, packaging type, year, country, etc. Furthermore, the team from Innova regularly make updates on trends they note in several of the categories. An Innova search was performed on introductions in the Netherlands between 2009 and 2018.

3 Results

3.1 Results Eurostat import data

The highest quantity of imported underground vegetables in 2017 came from China with 69.7 million kg. The majority of these imports (63.8%) concerns the import of ginger, which is followed by the import of garlic with 33.4%. High quantities of underground vegetables are also imported from Germany, Belgium and Luxemburg (Figure 1). Furthermore, Thailand is an important country for the import of ginger in the Netherlands (1.5 million kg). Fresh or chilled onion was mainly imported from Germany, Egypt and Poland with quantities of 48.2 million kg, 38.9 million kg and 35.3 million kg, respectively. Dried onion, imported in the Netherlands, was mainly coming from Egypt (5.1 million kg), Belgium (1.7 million kg) and India (1.4 million kg). Cassava originated, among others, from Brazil, Cameroon, Ghana, India, Indonesia and Nigeria. Therefore, data on hazards in cassava from these countries is considered relevant for this study.

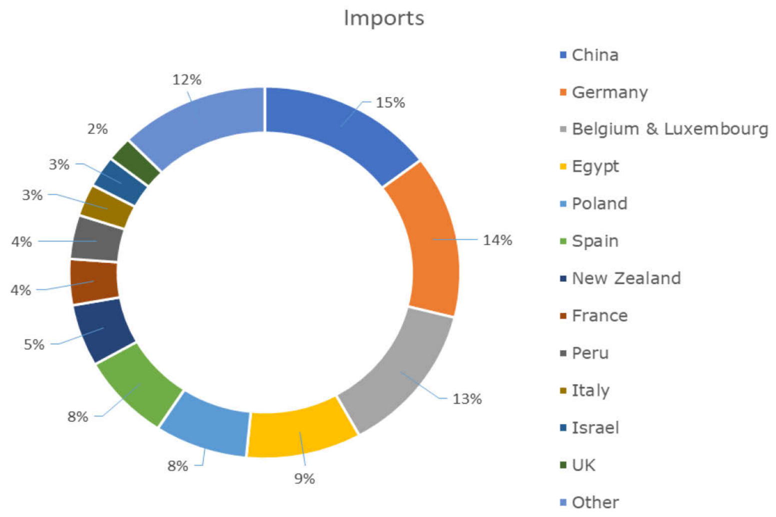

Figure 1 *Origin of imported underground vegetables.*

3.2 Results literature study

3.2.1 Results from Scopus and Web of Science

In total, 321 hits were found, 177 hits for Scopus and 144 hits for Web of Science. 84 duplicates were removed; 237 articles remained.

After screening the title, abstract and keywords, 97 articles were evaluated as relevant, 23 as maybe relevant and 117 as not relevant. The following topics were evaluated as not relevant (examples):

- Using Near Infrared Spectroscopy for differentiation between organic and commercial garlic;
- Pristine onion-like carbons (OLCs) as gas sensitive element;
- Generation of plant-derived biodiesel/biofuel (cassava peeling residues, alfalfa, radish, lettuce, wheatgrass);
- Peel garlic extract as corrosion inhibitor;
- Char for remediation of POP uptake in crops;
- Black root rot in carrots;

- Use of garlic for fish disease treatments;
- Antioxidant and antimicrobial effects of fennel/ garlic extracts;
- Microbial hazard analysis of commercial garlic;
- Estimation of sampling uncertainty for pesticide residues in root vegetables crops;
- Colour fixation during sweet potato flour processing;
- Identification of low cadmium cultivars of sweet potatoes;
- Consumers' willingness to pay for safety labels;
- Sensory characteristics of bread containing yacón concentrate;
- Waste management in Yamoussoukro (political capital of Cote d'Ivoire);
- PCBs in bank sediments and pharmaceutical active compounds along the Yamuna river;
- Effects on the metabolism of rats fed with sweet potato fibre;
- Use of vegetables (artichoke, onions) for phytoremediation of contaminated soils (cadmium, lead);
- Yam Nematode;
- Biodiversity: open-pollinated onion varieties;
- Sustainable agricultural production of shallots;
- Quality investigations of vegetables (appearance, organoleptic attributes);
- Sampling plans of mycotoxins in foods;
- Biosensors, based on plant enzymes, for detection of environmental contaminants;
- Use of officinal rhubarb as traditional Chinese medicine;
- Health promoting effects of lotus.

The full text of the 97 potentially relevant articles were read. In total, 59 references remained relevant after reading the full texts of the articles. Articles with the following topics were considered not relevant (examples):
- Microbiological hazards in underground vegetables;
- Compounds toxic to the plant and/or plant parts;
- Information on chemical composition (i.e. carbohydrate levels etc) of underground vegetables without a link to a chemical hazard;
- Limited information without clear data and/or units.

These 59 relevant articles were included in an Excel file, in which the details of the references were recorded, such as the chemical hazard, the country, exceedances of legal limits etc. This file is provided to NVWA BuRO as a supplementary file. A summary of all the information obtained is described in chapter 3.3. In case a hazard group retrieved a limited number of relevant papers, the 'maybe relevant' section in Endnote was browsed to search for additional information.

Relevant papers concerned in many cases the vegetables carrot (11 papers), cassava (16 papers) and radish (13 papers) and to a lesser extent asparagus (3 papers), bamboo (2 papers), beet root (1 paper), garlic (1 paper), ginger (1 paper), lotus (1 paper), onion (3 papers), spring onion (1 paper), sweet potato (3 papers), water chestnut (1 paper), yam (2 papers), taro (1 paper) and turnip (5 papers). No relevant papers were found for ahipa, arracacha, burdock, Chinese artichoke, chufa, daikon, elephant foot yam, gobo, jícama, komatsuna, laos, manioc, mooli, nopal, rutagaba, skirret, tigernut, ulluco, wasabi and welsh onion.

3.2.2 Results from Google search

The advanced search in Google resulted in 21 relevant hits (BfR: 3, EFSA: 6, FAO: 8, FAVV: 4), which were included in the accompanying Excel file. The total hits found in these websites are indicated in Annex 5.

The following topics (examples) were considered to be not relevant:
- Agenda of meetings, without valuable information given;
- Catalogue of project ideas;
- Chemical analysis of food, not focusing on hazardous substances;
- Guidance documents on how to process or how to grow vegetables;
- Guidance documents on how to reduce food waste;
- Guidance documents on healthy diets;

- Hazards for bees;
- Hygiene in the kitchen;
- List of stakeholders;
- Management guideline for food labelling;
- Microbiological hazards;
- Phytotoxic hazards that were not relevant for human health;
- Policy agenda;
- Proposal for setting standards on food products without safety parameters;
- Vegetables in general, without any relationship to the specific group 'Bulb, root, stem and tuber vegetables';
- Vegetable oils.

3.2.3 Results from the additional literature research

The hits obtained in the additional search were screened for their relevance in this study analogous to the procedure described in 2.3.1. Examples of topics that were considered as not relevant are:
- Cassava flour used as an alternative bread ingredient to wheat;
- PCBs in bank sediment and their ecotoxicological effects;
- Water quality in Tibet (without a link to irrigation water of food);
- Genebanking of taro;
- Ginger nanofibers in wound healing applications.

In total, 8 papers were included after the additional literature search.

More detailed information on the search terms used for the additional searches and the number of hits are given in Annex 6.

3.3 Overview of chemical hazards in underground vegetables

3.3.1 Heavy metals and other elements

From scientific literature, 20 relevant papers concerned heavy metals and other elements in underground vegetables. Many papers described the vegetables carrot and cassava. However, most papers discussed the metal content in radish (8 papers). Only 2 papers on heavy metals in radish contained occurrence data. The other papers described experiments, which investigated the translocation of heavy metals in radish for example. In order to downsize the number of papers, references that discussed the occurrence of metals in vegetables from countries The Netherlands did not import from in 2017 for all underground vegetables, were not included in this section. For example, it was decided to exclude a paper on heavy metals in garlic from Iran. The obtained information is, however, included in the accompanying Excel file.

3.3.1.1 **Uptake in bulbs, root, stem and tuber vegetables**

Underground vegetables can absorb heavy metals from the soil through their root systems. In this case, the quality of the soil greatly influences the quality of the food crops (Bhat et al., 2011). The literature search did not obtain papers on heavy metals in underground vegetables that investigated the uptake of heavy metals through air pollution.

Radish

Various experimental studies were found for radish, in which the effect of soil type, fertiliser alternatives and the type of irrigation water were studied on heavy metal concentrations. Results are discussed below.

The concentrations and translocation of <u>arsenic (As)</u> were assessed in various tissues of the radish plant as a result of uptake via the <u>soil</u>. The highest concentrations were found in the shoots, followed by the peel and consequently the flesh (Ngo et al., 2016). Villatoro-Pulido et al. (2009) also found higher concentrations of As, cadmium (Cd) and lead (Pb) in the shoots compared to the roots. In this study, the contaminated soil was taken from an experimental site called El Vicario, close to a mine in South Spain. The As, Cd and Pb concentrations in the control soil were 9.1 mg/kg dw, 0.2 mg/kg dw and 41.8 mg/kg dw, respectively. These values were respectively 74.8 mg/kg dw, 0.4 mg/kg dw and 83.2 mg/kg dw in the contaminated soil. The amount of As, Cd and Pb, which remained present in the roots in non-contaminated soils were 0.2 mg/kg, 0.2 mg/kg and 0.6 mg/kg dw, respectively. For the roots in contaminated soils the concentrations left were 1.2 mg/kg of As, 0.4 mg/kg of Cd and 0.2 mg/kg dw of Pb (Villatoro-Pulido et al., 2009).

The effect of soil type on As uptake by radish was studied in 2009 by Marconi et al. (2010). The plants were cultivated in sandy and clay soil and irrigated with control water containing 19 µg As/L in total and with water with added As up to a total concentration of 25 µg As/L or 85 µg As/L. Mean concentrations in radish grown in sandy soil were 0.7 mg/kg dw, 1.1 mg/kg dw, 2.0 mg/kg dw, respectively. Assuming a water content of radish of 95%, these values will be 32.5 µg/kg, 55 µg/kg, 97.5 µg/kg on fresh weight basis. For the radish grown in clay soil, the mean concentrations were measured to be 0.4 mg/kg dw, 0.8 mg/kg dw and 1.4 mg/kg dw, respectively. Converted into fresh weight, these concentrations would be 21.5 µg/kg, 38.0 µg/kg and 68.5 µg/kg. These results indicate that transfer from sandy soil to radish is higher than from clay to radish (Marconi et al., 2010).

Using concentrations found in both the soil and the plant, Ngo et al. (2016) estimated the bioaccumulation and translocation factors of As in radish. The bioaccumulation factor is a relative number to encompass to which extent a heavy metal is accumulated from the soil into the food crop. Some of the heavy metal content will not only accumulate at the place of uptake by the crop but will be transferred to other parts of the crop. This mobility of heavy metals in the food crop is called translocation. These values can help in the prediction of heavy metal uptake by food crops. According to the authors, food crops with a bioaccumulation factor <1 are considered as tolerant for the metal, since transfer of the metal from soil to roots is limited. The highest bioaccumulation factor found in this study was 0.008 and the highest translocation factor was 2.0 for As in radish. Remarkably, these values were measured in food crops grown on soils with the lowest As concentrations (Ngo et al., 2016).

Bhat et al. (2011) looked at the potential of sewage sludge as fertiliser on agricultural land for growing radish in India. Although growth of the crops was improved, the heavy metal content in radish was higher when sewage sludge was applied compared to application of fertilisers. For the latter situation, no Cd or Pb were detected in radish samples, whereas the highest concentration of Cd was measured to be 1.5 mg/kg dw in radish when 240 gram sewage sludge was applied on 1 kilogram soil. When higher quantities of sewage sludge were applied, up to 960 g/kg soil, these soils showed lower concentrations of Cd. Overall, higher concentrations of Cd were found in the shoots compared to the edible part of the plant. The experiments showed that when no sewage sludge was applied, no Pb was detected in the radish samples. The highest Pb concentration found was 0.28 mg/kg dw. This radish sample was grown in soil that was amended with 480 g/kg sewage sludge. Like for the Cd concentrations, almost all Pb concentrations were higher in shoots compared to the roots (Bhat et al., 2011). Radish showed to have a tolerance for Pb and Pb is barely translocated in the plant. After Pb was absorbed from the soil by the lateral roots, most of it retained there and translocation was only limited to the peel of the vegetable (Wang et al., 2015). Singh and Kumar (2014) also studied the uptake and translocation of Cd when sewage sludge was used for fertilisation of cultivation fields. Concentrations of Cd in radish root ranged from 0.02 mg/kg to 0.06 mg/kg. The authors concluded that the application of the sewage sludge, as used in this study, is not appropriate for the use of fertilising fields for cultivating food crops due to the presence of Cd (Singh and Kumar, 2014).

In a study on the effect of different types of treated wastewater for the use of irrigation, heavy metal content and other elements (chromium (Cr), copper (Cu), nickel (Ni) and zinc (Zn)) were investigated in radish. Conventional irrigation water was used as control during this study, which is conventionally applied during cultivation. The other wastewaters used in this experiment, were treated with primary sedimentation for primary treated wastewater (PTW), with secondary sedimentation and with a treatment with compact packed bed biofilter for secondary treated wastewater (STW), and after sand filtration and a chlorination process for tertiary wastewater (TTW). Cr was not detected in radish in any of the applications. For Cu, mean concentrations in radish were 25.1 mg/kg dw for the control, 23.5 mg/kg dw for the PTW batch, 26.8 mg/kg dw for the STW batch and 23.9 mg/kg dw for the TTW batch. Mean concentrations of Ni in radish were 0.3 mg/kg dw for both the control batch and the PTW batch and 0.4 mg/kg dw for the STW and the TTW batches. The mean concentrations of Zn decreased from the control radish to radishes from PTW, STW and TTW batches, with values of 19.2 mg/kg dw, 18.7 mg/kg dw, 17.4 mg/kg dw and 17.3 mg/kg dw, respectively. The authors concluded that irrigation with the different types of treated wastewaters did not exert a significant effect on the heavy metal content of the cultivated radishes (Petousi et al., 2014).

Carrots
North-western China is a persistently dry area, which is used for desert oasis farming. For this purpose, sewage is often applied to irrigate the dry land. In an experiment, carrots were cultivated in soil coming from the desert oasis. The experimental soils were contaminated with <u>Cd</u> and <u>Ni</u> in concentrations ranging from 0.4 mg/kg to 7.5 mg/kg Cd and from 60 mg/kg to 1100 mg/kg Ni. For the control soil, no addition with Cd nor Ni was carried out. Cd was gradually taken up by the carrots and accumulated in the plant. The highest Cd concentration in the root during this study was 9.2 mg/kg when the soil was contaminated with 7.5 mg/kg Cd. Ni concentrations ranged from 2.5 mg/kg to 101.5 mg/kg, for which the latter soil was contaminated with 350 mg/kg. No analyses were done for the soil batches that were contaminated with 500 mg/kg, 750 mg/kg and 1100 mg/kg. Notably, all concentrations measured in the leaves of the plants were higher than those measured in the roots. This indicates that carrots may easily translocate the Cd, which is confirmed by the fact that the translocation factor was above 1 (Wang et al., 2012).

A recent research in the Netherlands showed that the Cd uptake in carrots and potato was not affected by using Cd-rich fertilisers during 1 harvest cycle. Cd uptake was more affected by soil properties (such as pH and organic matter) and Cd levels in the soil (Römkens et al., 2018). The latter factors have previously been included in models along with crop constants in order to predict Cd and Pb concentrations in underground vegetables when grown in contaminated soils (Franz et al., 2008; Otte et al., 2011).

Lilli et al. (2017) investigated the relationship between the carbon content of the soil and the uptake and translocation of <u>Cr</u> in carrots. This was simulated by using compost on the cultivation field. For dose 1, 50,000 kg compost per ha was used, for dose 2, 100,000 kg compost per ha and no compost was used for the control. Cr concentrations measured in carrots were 0.2 mg/kg for the control, 0.3 mg/kg for dose 1 and 0.2 mg/kg for dose 2. Although Cr was found in the leaves of the carrot plant, the presence of Cr in the carrots was limited. Higher carbon contents in the soil showed higher mobility of Cr in carrot. The authors calculated that the carcinogenic risk for the US consumer would be 0.077-0.24 in a million and concluded that the consumption of carrots does not trigger adverse effects to human health for Cr (Lilli et al., 2017).

In another experimental study, soils were contaminated with <u>Pb</u> and <u>As</u> to test the accumulation of these heavy metals in carrots. The study concluded that Pb and As are translocated to and accumulates in the edible part of the carrot. Pb is stored for the largest part in the root, while As is stored primarily in the peel (Codling et al., 2015).

Turnip
Li et al. (2016) examined <u>Cd</u> concentrations in the aboveground and underground part of turnip. Seeds of turnip plants from different origins within China were planted under experimental conditions and, when in plant stage, $CdCl_2$ was added to the soil. Concentrations in the underground part ranged from 8.2 mg/kg dw to 81.5 mg/kg dw. For all the samples, the aboveground parts had higher concentrations than the underground part with concentrations ranging from 52.9 mg/kg dw to 147.0 mg/kg dw. These values are higher than the Cd concentrations that were found in the soil, showing that turnip has a high capability for Cd accumulation, especially in the leaves (Li et al., 2016).

3.3.1.2 **Occurrence data**

Together with tomato, maize, ridge gourd, bottle gourd, brinjal and lady finger, grown in New Delhi, India, radish was tested on the presence of As. The average concentration was 2.4 mg/kg dw, which was the highest concentration in all the vegetables tested in this study. Consumption of radish with such concentrations of As showed to exceed the provisional maximum tolerable daily intakes (PMTDI) established by the WHO, which was 2.1 µg/kg bw/day for inorganic As for the Indian consumer. Although radish had the highest concentrations, tomato contributes more to the exceedance of this limit, due to the higher estimated daily intake (EDI) for the Indian consumer, since radish is only consumed seasonally (Mishra et al., 2014). It is important to note that the PTWI for As is found no longer appropriate, since As should be speciated and a limit on solely inorganic As should be established. However, occurrence data on speciated As is scarce (EFSA, 2014b). In a review on As, it became clear that As mainly accumulates in roots, followed by stems and leaves and lastly in fruits. A positive linear correlation was seen in the As content of the soil and in underground vegetables. This group of vegetables also showed higher As concentrations, compared to leafy and fruity vegetables. The average concentrations of total As found in several studies from India and Taiwan were 338 µg/kg in carrot, 165.7 µg/kg in onion, 374.6 µg/kg in radish and 191.4 µg/kg in sweet potato. Notably, the samples originating from India had higher As concentrations than the samples from Taiwan (Arslan et al., 2017).

Alongside the Yangtze River in China, lotus roots are cultivated. In a survey, 55 samples of lotus roots were tested on the presence of the heavy metals As, Cd, Cr, Cu, Pb and Zn. Mean concentrations found in these samples were 4.8 mg/kg, 1.5 mg/kg, 17.3 mg/kg, 32.2 mg/kg, 15.0 mg/kg and 88.4 mg/kg, respectively. According to the authors, the consumption of lotus roots grown in rural ponds would pose a risk to human health (Luo et al., 2017). Another Chinese study took samples of lotus roots in September 2006 and the presence of the metals Cd, Cu, Zn and Pb was tested. The results showed mean concentrations of 0.02 mg/kg for Cd, 7.13 mg/kg for Cu, 0.88 mg/kg for Pb and 14.38 mg/kg for Zn. These concentrations were below the Chinese MLs for contaminants in fresh non-leafy vegetables (Liu et al., 2012).

In a study on Pb in cassava flour from regions alongside the Tapajós River in Brazil, the mean concentration was 0.3 mg/kg. Based on the concentrations found, the EDI was calculated for the populations that live alongside the river. This EDI was compared to the bench mark dose lower confidence limit (BMDL) for neurotoxicity, which was established by EFSA. The EDI of Pb through the consumption of cassava flour was calculated to be 79 µg/d, which is higher than the BMDL of 35 µg/d for a European adult (bw=70 kg). Therefore, cassava flour from those regions can be considered as a concern to human health (Carneiro et al., 2013). Another study on cassava and cassava crisps from Ghana tested for the metals and elements As, Cu, Fe, Hg, Pb and Zn. As and Pb were not detected in samples of both raw cassava and cassava crisps. The levels of Hg were not quantifiable in both products. Mean concentrations in raw cassava were 2.05 mg/kg fw for Cu, 14.59 mg/kg fw for Fe and 6.49 mg/kg fw for Zn. Mean concentrations of 1.74 mg/kg fw, 16.37 mg/kg fw and 7.44 mg/kg fw were found for Cu, Fe and Zn, respectively in cassava crisps (Ofori et al., 2016). Cu, Fe and Zn are essential elements that are needed at minimum daily intakes for an optimal functioning of the human body. However, they also have tolerable upper intake limits (ULs). The UL for copper and zinc are 5 mg/d and 25 mg/d (both for an adult), respectively. An UL for iron is not established, but adverse effects have been reported after an ingestion of 50-60 mg/d of iron by an adult (EFSA, 2006).

In a study on wild asparagus from Sardegna, Italy, the presence of As, Cd, Co, Cu, Fe, Ni, Pb and Zn was measured. Median concentrations found in asparagus from uncontaminated (n=20) areas were (in dw): 0.02 mg/kg, 0.01 mg/kg, 0.05 mg/kg, 10 mg/kg, 46 mg/kg, 2.9 mg/kg, 0.1 mg/kg and 47 mg/kg, respectively. When recalculating to fresh weight, half of these samples showed a higher Pb concentration than the EU ML, which was the case for a quarter of the samples for Cd. Compared to the other elements, the highest intake relative to the HBGV was found for Cd. Asparagus collected in mining-related areas showed median concentrations (in dw) of 0.1 mg/kg, 1.4 mg/kg, 0.1 mg/kg, 11 mg/kg, 50 mg/kg, 4.2 mg/kg, 0.2 mg/kg and 58 mg/kg for As, Cd, Co, Cu, Fe, Ni, Pb and Zn, respectively. Of the fourteen samples from mining-related areas, eleven exceeded the EU ML for Cd and nine for Pb. The EDI was calculated based on Italian consumption data assuming an average consumption of vegetables including asparagus of 37.3 gram per day. The established EDI's were compared to available HBGVs or guidelines (established by EFSA or WHO) for As, Cd, Cu, Ni, Pb, Sb and Zn. These comparisons showed that the ratio for all elements was below 1 meaning no health issues are to be expected for the tested heavy metals and elements due to the consumption of asparagus (Biddau and Cidu, 2017).

A study in Czech Republic compared the heavy metal content (Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) in 76 carrot samples, which were cultivated in private gardens, in 71 conventionally grown carrot samples and in 71 samples of organic carrots. The samples were collected from the market during the years 2012 and 2013. Mean concentrations found in conventionally grown carrots were 12.3 mg/kg for Al, 0.2 mg/kg for As, 0.1 mg/kg for Cd, 0.1 mg/kg for Cr, 0.9 mg/kg for Cu, 5.2 mg/kg for Fe, 1.7 mg/kg for Mn, 1.6 mg/kg for Ni, 0.1 mg/kg for Pb and 6.1 mg/kg for Zn. These values were 18.5 mg/kg for Al, 0.9 mg/kg for As, 0.1 mg/kg for Cd, 0.1 mg/kg for Cr, 0.6 mg/kg for Cu, 5.0 mg/kg for Fe, 0.8 mg/kg for Mn, 0.8 mg/kg for Ni, <0.1 mg/kg for Pb and 6.7 mg/kg for Zn in organic carrots. Carrots grown in private gardens showed concentrations of 20.3 mg/kg for Al, 0.2 mg/kg for As, <0.1 mg/kg for Cd, 0.6 mg/kg for Cr, 1.0 mg/kg for Cu, 13.1 mg/kg for Fe, 1.3 mg/kg for Mn, 1.2 mg/kg for Ni, 0.1 mg/kg for Pb and 6.9 mg/kg for Zn. Carrots exceeding the regulatory limits for heavy metals were observed primarily in samples grown in private gardens. Organic carrots had the lowest number of ML exceedances (Krejčová et al., 2016).

In a scientific advice, the Federal Agency for the Safety of the Food Chain in Belgium (FAVV) urges for separate action limits for Cr in food. Since the toxicity profile of Cr^{3+} differs much from that of Cr^{6+}, which is carcinogenic and genotoxic, FAVV suggests separate action limits for Cr^{3+} and Cr^{6+}, which are 70 mg/kg and 20 µg/kg, respectively for root and tuber vegetables (excluding starchy- and sugar-), 200 mg/kg and 80 µg/kg, respectively for bulb vegetables and 80 mg/kg and 30 µg/kg, respectively for stem vegetables. Classification of vegetables used by FAVV is given in Annex 3. The currently available data on Cr is primarily for total Cr. The advice also reports the concentrations of total Cr for 21 carrot samples. The average concentration of total Cr is 10 µg/kg, with a minimum below 8 µg/kg and a maximum of 93 µg/kg. These concentrations are below the action limits for Cr^{3+} as indicated above. In foodstuffs, Cr3+ will predominantly be found since that is the most stable and most common oxidation level in these products (FAVV, 2018).

In the summer of 2017, 30 onion samples and samples from soil from the United Kingdom were tested on the metals and elements As, Cr, Cu, Pb and Zn. Onions contained concentrations of <0.7 mg As/kg, <0.6 mg Cr/kg, <1 mg Cu/kg, <0.4 mg Pb/kg and <10 mg Zn/kg. Although high concentrations of heavy metals were measured in soil samples and did exceed UK and EU guidelines for soil, the concentrations found in onions did not result in an exceedance of the FAO/WHO intake limits. Furthermore, risk assessment calculations did not show human health effects due to the consumption of these onions (Weber et al., 2019).

3.3.1.3 **Conclusion**

The literature study showed that the underground vegetables carrot, radish and turnip were able to take up metals present in the soil. The experimental studies showed that higher metal concentrations were found in the aboveground part than in the underground parts. The occurrence data showed that Cd and Pb concentrations sometimes exceeded the EU MLs. Furthermore, As was frequently detected in underground vegetables. As mainly accumulates in root vegetables followed by stem vegetables, then leafy vegetables and finally in fruiting vegetables.

3.3.2 Persistent organic pollutants

Persistent organic pollutants (POPs) are present in the environment and can be taken up by vegetables during cultivation. The literature search only resulted in one study on perfluoroalkyl compounds. No relevant hits on POPs were found in the Google Search. An additional search on perfluor compounds, dioxins and PCBs resulted in one EFSA report on PFAS. No information was found on dioxins, PCBs and other POPs.

PFAS are substances used for several applications in industry (e.g. textile industry) due to their repulsive characteristics. Their production and application can result in presence in water, air and soil.

In the latter case, PFAS can be taken up through the root system of underground vegetables (RIVM, 2018). Aparicio et al (2018) reported a limited number of analysis on perfluoroalkyl substances (PFAS). The following six PFAS were analysed in carrots and turnips: perfluorobutanoic acid (PFBuA), perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), perfluroroheptanoic acid (PFHpA), perflurorooctanoic acid (PFOA), perfluorooctanesul-fonic acid (PFOS). From both vegetables, 4 samples were collected at a local market in Spain. Concentration ranges found in carrots were: 1.20-2.7 µg/kg dw (PFBuA), 0.3-0.5 µg/kg dw (PFPeA), 0.8-1.6 µg/kg dw (PFHxA), 0.3-1.0 µg/kg dw (PFHpA), 0.8-1.3 µg/kg dw (PFOA), 0.6-0.8 µg/kg dw (PFOS). The concentrations found in the turnip samples ranged from 3.3-4.5 µg/kg dw for PFBuA, 0.7-1.0 µg/kg dw for PFPeA, 2.1-2.7 µg/kg dw PFHxA, 1.5-1.9 µg/kg dw for PFHpA, 1.6-1.9 µg/kg dw for PFOA, 0.9-1.2 µg/kg dw for PFOS. All PFAS concentrations were higher in turnip than in carrot (Aparicio et al., 2018). EFSA studied the occurrence of two PFAS, namely PFOA and PFOS in food and the risk related to this in a broad spectrum of food products for the period 2011-2016. PFOA was tested in 75 samples of onion in the EU and had a mean upper bound (UB) concentration of 248 ng/kg. For PFOS, 77 onion samples were tested in the EU, which had a mean UB concentration of 237 ng/kg. In the category root vegetables, samples of beetroot (n=8), carrot (n=118), celeriac (n=4), parsley root (n=1), parsnip (n=2), radish (n=15), salsify (n=5), swede (n=3) and turnip (n=5) were tested on the presence of PFOA. The mean UB concentration measured in these samples were 813 ng/kg, 240 ng/kg, 750 ng/kg, 500 ng/kg, 1000 ng/kg, 169 ng/kg, 500 ng/kg, 833 ng/kg and 48 ng/kg, respectively. Except for carrot (n=123), the same number of samples were tested for the presence of PFOS. Mean UB concentrations were 625 ng/kg in beetroot, 219 ng/kg in carrot, 750 ng/kg in celeriac, 500 ng/kg in parsley root, 1000 ng/kg in parsnip, 154 ng/kg in radish, 500 ng/kg in salsify, 833 ng/kg in swede and 51 ng/kg in turnip. The stem vegetables collected for measurement of PFOA were 63 samples of asparagus, 2 samples of fennel, 8 samples of leek one sample of rhubarb. The mean UB bound concentrations of PFOA in these samples were 582 ng/kg, 18 ng/kg, 103 ng/kg and 500 ng/kg, respectively. The number of samples tested for PFOS were equal in case of rhubarb and leek and was 66 for asparagus and 4 for fennel. The samples of asparagus, fennel, leek and rhubarb showed PFOS concentrations of 517 ng/kg, 15 ng/kg, 61 ng/kg and 500 ng/kg, respectively. Sweet potatoes were sampled for the group tuber vegetables, with 3 samples. The mean UB concentration was 833 ng/kg for both PFOA and PFOS each. In the report of 2018, EFSA established the current tolerable weekly intake (TWI) for PFOA and PFOS, which are 6 ng/kg bw and 13 ng/kg bw, respectively. These TWIs are currently under review. The main contributors to PFOS intake were fish and other seafood, meat and meat products and eggs and egg products. For PFOA, milk and dairy products, drinking water and fish and other seafood were the main contributors (EFSA, 2018e).

3.3.2.1 **Conclusion**

Only one study reported the presence of several PFAS in carrots and turnip, in which all concentrations of PFAS were higher in turnip than in carrot. An EFSA report showed that the highest mean UB concentrations for both PFOA and PFOS were reported in parsnip. However, according to EFSA, underground vegetables are not the main contributors to the dietary intake of these compounds.

3.3.3 Polycyclic aromatic hydrocarbons (PAHs)

Three papers were found in the literature study for this hazard group. Two papers described experiments on the uptake of PAHs, both in radish. One review paper compared all the data from previous reports on the occurrence of PAHs in several vegetables. The presence of PAHs found in underground vegetables is discussed below.

3.3.3.1 **Uptake in bulbs, root, stem and tuber vegetables**

Humans can be exposed to PAHs through smoking. Besides that, food is a main contributor to the exposure to these compounds (Paris et al., 2018). PAHs are chemical compounds developed after the combustion of e.g. wood, coal, gasoline and/or oil (CDC, 2009). These industrial processes can lead to environmental contamination and as such can accumulate in food. Furthermore, PAHs may be formed during food preparation such as frying and smoking.

Two experimental studies described the uptake of PAHs in radish. A study in China in 2018 assessed polycyclic aromatic hydrocarbons (PAHs) in radish, specifically naphthalene (NAP), acenaphthene

(ACE), acenaphthylene (ACY), fluorene (FLU), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLA), pyrene (PYR), benz(a)anthracene (BaA), chrysene (CHR), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), benzo(a)pyrene (BaP), dibenzo(a,h)anthracene (DBA), indeno(1,2,3- d)pyrene (IPY), benzo(ghi)perylene (BPE). Although PAH concentrations in soils were higher than in the vegetables, concentrations up to 982.3 μg/kg for the sum of the PAH16 were detected in radish. Overall, the concentrations measured in the above parts of the radish plant were lower than in the edible part, the radish itself. This indicates that uptake of the PAHs in this case is through the network of roots in the soil. According to the authors, the presence of PAHs in radish poses a carcinogenic risk to consumers (Guo et al., 2018).

Petousi et al. (2014) tested the concentration of 10 PAHs in radishes irrigated with different irrigation waters, namely tap water (functioning as control), primary treated water, secondary treated water and tertiary treated water. Secondary treated wastewater is wastewater from the second step during sewage or wastewater treatment, where dissolved and suspended biological matter is removed and tertiary treated wastewater is water from the third and final step during sewage or wastewater treatment that improves the quality before reuse, recycling, or entry to the environment; this step can remove inorganic compounds among other substances like nitrogen and phosphorus. The tested PAHs were FLU, PHE, FLA, ANT, PYR, CHR, BaA, BaP, BbF and BkF. In all cases, the PAH pyrene was found at the highest concentrations. The total concentrations of the 10 PAHs were 61.0 μg/kg, 64.9 μg/kg, 65.9 μg/kg, 77.7 μg/kg for the radishes irrigated with tap water, tertiary treated water, secondary treated water and primary treated water, respectively (Petousi et al., 2014).

3.3.3.2 **Occurrence data**

In an overview given by Paris et al. (2018), occurrence data on PAH8 (sum of the heavy PAHs BaP, BaA, BbF, BkF, BPE, CHR, DBA, and IPY) are given for several vegetables. The underground vegetables considered in this study were carrot, garlic, kohlrabi, leek, onion, radish, shallot and turnip. The highest concentration of PAH8, found in carrots, was 18.9 μg/kg fw found in samples from China. PAH8 was <0.1 μg/kg fw for carrots from Denmark. In general, concentrations were higher in the peel of the carrot rather than in the core. Garlic and onions from Romania were tested on the presence of PAHs that were cultivated in urban and rural areas. PAH8 concentrations were 2.6 μg/kg fw for the urban garlic and 2.7 μg/kg fw for rural garlic. Urban onions contained 1.9 μg/kg fw PAH8 and below the LOQ for rural onion. Kohlrabi contained between 0.6 μg/kg and 1.7 μg/kg fw PAH8, originating from Germany, and leek between 0.1 μg/kg and 0.8 μg/kg fw PAH16, originating from Greece. The PAH8 concentrations found in turnip from Pakistan were 6.3 μg/kg fw in the core and 8.7 μg/kg fw in the peel. Radish samples from the South of China contained the highest PAH concentrations with a PAH8 concentration of 4.5 μg/kg fw. The total PAH8 concentration in shallots from this region was 48.8 μg/kg fw. It should be noted that these high concentrations were found near an electronic-waste burning site. In general, PAH concentrations in vegetables are low (between 0.01 and 0.5 μg/kg fw). However, depending on the location, high concentrations (> 5 μg/kg fw) may be found. PAH levels, in general, are higher in urban and industrial areas than in rural areas (Paris et al., 2018).

3.3.3.3 **Conclusion**

An experiment in China showed that PAHs can be taken up through the radish roots. However, concentrations in the leaves were higher than in the edible part of the plant. An overview paper showed that highest concentrations were found in vegetables originating from China with highest levels in shallots.

3.3.4 Nitrate

Nitrate can be absorbed from the soil, especially by the roots of the crop. The type of fertiliser can impact the uptake of nitrate by vegetables (FAVV, 2014a).

Data on the occurrence of nitrate in underground vegetables was provided in one paper obtained during the literature search. An additional search resulted in two other papers, which contained occurrence data on nitrate in underground vegetables and one paper on the effect of processing.

3.3.4.1 **Occurrence data**

In a Scientific Advice given by the FAVV, nitrate was one of the hazards studied for a scientific approach for recalls of food products. The highest concentration, found in carrot samples from 2012, was 140 mg/kg. Nevertheless, carrot is not the predominant nitrate containing food product; leafy vegetables (e.g. spinach) usually contain higher nitrate concentrations (for more detailed information, see (Banach et al., 2019)). The toxicological reference value for the acute risk of nitrate is 15 mg/kg bw/day (FAVV, 2014a).

In Hargelsberg, Austria, 16 samples of beetroot juices were collected in 2013 and tested for the nitrate content. These juices showed a mean concentration of 1275 mg/L. Besides the commercial juices, 7 different beetroot cultivars were processed into juice and the nitrate content of these juices were tested as well. The mean concentration of the fresh juices was 1970 mg/L. The highest nitrate concentration was detected in the cultivar Mona Lisa. The nitrate concentration, measured in this cultivar was 4626 mg/L (Wruss et al., 2015). Also Lidder and Webb (2013) reported nitrate concentrations in underground vegetables. The highest concentration was observed in radish with 1868 mg/kg. This was followed by 1459 mg/kg in beetroot, 624 mg/kg in turnip, 398 mg/kg in leek, 353 mg/kg in spring onion, 222 mg/kg in carrot, 183 mg/kg in garlic and 87 mg/kg in onion. The ADI for nitrate established by EFSA is 3.7 mg/kg bw/day. Based on UK consumption data, the consumption of 80 gram of radish or beetroot by an adult (bw=70 kg) can already contribute over 50% to the ADI (Lidder and Webb, 2013). Similar findings were observed in the study by Santamaria (2006), in which vegetables were classified according to the nitrate content. The classes of nitrate content were 'very low' with a concentration below 200 mg/kg fw, 'low' with a concentration between 200-500 mg/kg fw, 'middle' with a concentration between 500-1000 mg/kg fw. Concentrations between 1000 and 2500 mg/kg fw were classified as 'high' in nitrate content and as 'very high' with concentrations above 2500 mg/kg fw. The vegetables asparagus, garlic, onion and sweet potato fell within the class 'very low'. Carrot was classified as 'low' nitrate content and turnip as 'middle' nitrate content. In the class 'high' were celeriac, fennel, kohlrabi and leek. Radish and beetroot were classified as 'very high' in nitrate content (Santamaria, 2006).

3.3.4.2 **Effects of processing**

In several carrot cultivars, the nitrate contents were compared among fresh carrots, frozen carrots, carrots in jars and dried carrots. The average nitrate concentrations were 242.4 mg/kg fw in fresh carrots, 176.4 mg/kg fw in frozen carrots, 100.7 mg/kg fw in jarred carrots and 1126.8 mg/kg fw in dried carrots. The lowest decrease in nitrate content during processing was detected in the Karotan cultivar. Nevertheless, this cultivar did not have the highest concentrations of nitrate in the end. The highest nitrate concentrations were in the cultivars Flacoro and Koral for fresh, frozen and jarred carrots. The highest concentration was observed in dried carrot, which was the Karotan cultivar. The consumption of 55 gram thereof, which is based on Polish consumption data, result in a nitrate intake of 75.8 mg. The authors concluded that this would be 34% of the ADI for an adult with a body weight of 60 kg. Furthermore, the authors found that spraying a solution with magnesium (3%) on the leaves of carrot plants lowers the nitrate content (Wszelaczyńska et al., 2017).

Various studies have shown reduction of nitrate levels when vegetables are boiled in water. Peas, cabbage, beans, carrots, potatoes and spinach, endives and celery leaves lost between 16 to 79%, of the nitrate, respectively, during cooking (Abo Bakr et al., 1986; Schuster and Lee, 1987; Dejonckheere et al., 1994). The content of nitrate and nitrite decreased similarly after boiling by about 50% in carrot, parsley-root, celery and potatoes (Roszczenko et al., 2001).

3.3.4.3 **Conclusion**

The presence of nitrate was reported in carrot, garlic, leek, onion, spring onion and turnip. However, highest concentrations were found in beetroot (1459 mg/kg) and radish (1868 mg/kg). The consumption of 80 gram radish or beetroot by an adult can contribute more than 50% to the ADI for nitrate. Processing of underground vegetables may affect nitrate concentrations, since studies showed that levels in carrot decreased after boiling, freezing, conserving or drying.

3.3.5 Pharmaceutical compounds

The literature study only retrieved experimental studies on the uptake of pharmaceutical compounds in underground vegetables.

3.3.5.1 **Uptake in bulbs, root, stem and tuber vegetables**

The use of medicine and the subsequent urinary excretion can result in contamination of the environment with respect to pharmaceutical compounds. Some pharmaceutical compounds are not removed in waste water treatment and thus end up in the environment. Subsequent uptake by underground vegetables may result in unintentional human exposure to these kinds of compounds (Malchi et al., 2014). Berendonk (2018) concluded from a literature study that leafy vegetables showed the greatest ability to take up pharmaceutical compounds and root vegetables are second-best in taking up pharmaceutical compounds, such as antibiotics. These are followed by cereal and other food crops and fruiting vegetables, in decreasing order.

The uptake of the antibiotic nitrofurans (furaltadone, furazolidone, nitrofurantoin, nitrofurazone) was studied in spring onion, which was grown in soil contaminated with nitrofuran. The experiment showed that nitrofurans are taken up by the plant and accumulates in the edible tissue. Accumulation was mainly in the bulb, but it was also observed in the leaves. The amount of nitrofurans decreased to the same extent as the reduction of nitrofuran contamination in the soil. Apart from nitrofurans, also the presence of its metabolites was tested, which showed that the soil did not contain metabolites, whereas metabolites were present in the root as well as in the leaves of spring onion. This indicates that spring onion has hydrolysis capability to nitrofurans and degrades the antibiotic into its metabolites (Wang et al., 2017). Mendez et al. (2016) also studied the behaviour of an antimicrobial in onion. In this study, the irrigation water was contaminated with various triclosan in the concentrations 0.015 µg/L, 0.150 µg/L and 1.500 µg/L. Triclosan concentrations found in onions were 401 µg/kg, 435 µg/kg and 432 µg/kg, respectively. Although the triclosan concentration in the irrigation water increased by tenfold, the triclosan concentrations in onions did not increase to the same extent. Nevertheless, the experiments showed that uptake is possible. Although triclosan levels degrade over time in the soil, this substance will remain in the soil when it is continuously irrigated with contaminated water (Mendez et al., 2016).

In another experiment, both ionic and non-ionic pharmaceutical compounds were tested in carrots and sweet potatoes. The crops were irrigated with treated wastewater to which 13 pharmaceutical compounds were added. The ionic pharmaceutical compounds comprised lamotrigine, caffeine, carbamazepine and it metabolite 10,11-epoxycarbamazepine. The non-ionic pharmaceutical compounds in this study were bezafibrate, clofibric acid, diclofenac, gemfibrozil, ibuprofen, ketoprofen, metoprolol, naproxen, sildenafil, sulfamethoxazole. Among these, diclofenac, ibuprofen, ketoprofen and naproxen were not found at concentrations above the LOD in any plant tissue. Gemfibrozil and metoprolol were also not detected in any edible plant tissue. Detectable levels of ionic pharmaceutical compounds in the edible plant tissue of carrots were 1.0 µg/kg fw (lamotrigine), 0.3 µg/kg fw (caffeine), 0.8 µg/kg fw (carbamazepine) and 0.2 µg/kg fw (10,11-epoxycarbamazepine). The concentrations in sweet potato were 0.3 µg/kg fw (caffeine), 0.1 µg/kg fw (carbamazepine), <0.1 µg/kg fw (10,11-epoxycarbamazepine) and not detected for lamotrigine. All in all, higher concentrations were found in the leaves compared to those in the edible parts of the plants, which suggests that the mobility of compounds is higher in these vegetables than in the bulb vegetables in studies described previously. Notably, the concentrations of carbamazepine in leaves were significantly lower than those of its metabolite 10,11-epoxycarbamazepine. The authors used the threshold of toxicological concern (TTC) principle to perform risk assessments for an adult (bw=70 kg) and a toddler (bw= 25 kg). This showed that when an adult consumes 180 grams of carrot, the TTC for lamotrigine (i.e. 2.5 ng/kg bw/day) would be exceeded based on the given concentrations. For toddlers, this was reached at 60 grams of carrot. The TTC for the metabolite 10,11-epoxycarbamazepine would be exceeded with a consumption of 250 gram by a toddler. For the other pharmaceutical compounds, consuming quantities between 710 gram and 905 kg of sweet potato or carrot are required to reach the TTCs (Malchi et al., 2014).

Another study assessed the risk of several pharmaceutical compounds on the basis of previously reported experimental data. Hazard quotients (HQs) were calculated with the help of the highest value of the compound found in the edible tissue of vegetable plants, the estimated daily intake based on US consumption data and the amount of product that would lead to exceedance of the ADI. The authors of this study calculated the ADI on the basis of available toxicological endpoints (e.g. NOAEL). Concentrations of pharmaceutical compounds were mainly reported in carrot. The maximum concentrations reported for this vegetable were 0.1 µg/kg dw triamterene, 0.2 µg/kg dw 10,11-epoxycarbamazepine, 2.2 µg/kg dw ciprofloxacin, 4.0 µg/kg dw DEET, 4.5 µg/kg dw norfloxacin and 336 mg/kg dw ambrettolide. Concentrations of two pharmaceutical compounds were reported in garlic, i.e. for monensin (4.0 µg/kg dw) and virginiamycin (6.6 µg/kg dw). Tylosin was detected in onion in a concentration of 2 µg/kg dw. In radish, concentrations of triclosan with 9200 µg/kg dw, gentamicin with 81 µg/kg dw and monensin with 4 µg/kg dw were found. Looking at the single compounds in underground vegetables, none of the HQs for an adult were higher than 0.1. For toddlers, a HQ of 0.2 was estimated for triclosan in radish (Prosser and Sibley, 2015). However, some criticism was developed towards this study. Malchi et al. (2015) argued that the diversity of the experimental set-up of the studies used for the risk assessment, makes it difficult to compare and classify the results (Malchi et al., 2015).

In an experimental study, carrots were tested on the presence of several veterinary medicines, such as amoxicillin, diazinon, enrofloxacin, florfenicol, levamisole, oxytetracycline, phenylbutazone, sulfadiazine, trimethoprim and tylosin. The carrots were grown in soil that was spiked with 1 mg/kg for each pharmaceutical compound. The compound amoxicillin was dissipated in the soil within one day. The concentrations of the pharmaceutical compounds levamisole, oxytetracycline, phenylbutazone, sulfadiazine and tylosin were below the detection limit. For the detectable levels of pharmaceutical compounds found in carrot, most concentrations were higher in the peel of the carrot than the whole carrot. Except for trimethoprim, which had a mean concentration of 1 µg/kg in the peel and 5.3 µg/kg in the carrot as a whole. Mean concentrations detected in the peel were 24 µg/kg for diazinon, 8.5 µg/kg for enrofloxacin and 38 µg/kg for florfenicol. Mean concentrations in the whole carrots were 13 µg/kg, 2.8 µg/kg, 5 µg/kg for diazinon, enrofloxacin and florfenicol, respectively. The authors also evaluated to what extent these residues in carrots would impact human health. An average daily intake of 333 g underground vegetables (potatoes and bulb vegetables) was used to determine the EDI using the concentrations found in carrots. The highest contribution to the ADI was found for the compound levamisole (based on an ADI of 6 µg/kg bw/day). Nevertheless, this accounted for less than 10% of the ADI (Boxall et al., 2006).

Another experiment tested the interactions between pharmaceutical compounds and heavy metals in beets, that were irrigated with wastewater. Interestingly for this research is that the wastewater in this experiment naturally contained pharmaceutical compounds. So, the irrigation water was not spiked with the pharmaceutical compounds. Beet root plants were irrigated with this waste water. Some of the pharmaceutical compounds, present in the waste water, were also detected in the beet root samples (n=28). The concentrations found in the waste water were 153 ng/L of caffeine, 12 ng/L of bisoprolol, 116 ng/L of carbamazepine, 75 ng/L of clarithromycin, 104 ng/L of metoprolol, 40 ng/L of sulfamethoxazole, 29 ng/L of trimethoprim. The concentrations of the pharmaceutical compounds present in the beetroots were 0.81 µg/kg dw of caffeine, 0.13 µg/kg dw bisoprolol, 0.31 µg/kg dw metoprolol, 0.27 µg/kg dw sulfamethoxazole, 0.22 µg/kg dw trimethoprim. The pharmaceutical compounds carbamazepine and clarithromycin were not detected in the beet roots (Papaioannou et al., 2020).

3.3.5.2 **Occurrence data**

The literature review, the advanced search in Google and the additional search did not result in occurrence data for this hazard group in underground vegetables.

3.3.5.3 **Conclusion**

Several experimental studies showed that underground vegetables are able to absorb pharmaceutical compounds from the soil or via irrigation water. One of the studies indicated that consumption of carrot would lead to an exceedance of the TTC for the compounds lamotrigine and 10,11-epoxycarbamazepine. No occurrence data was available on this class of hazards in underground vegetables.

3.3.6 Radionuclides

Radionuclides are naturally present in the earth's crust and can lead to environmental contamination through the refinery of metals, fossil fuel combustion or other industrial activities. Also nuclear incidents, such as Chernobyl, have a strong impact on this sort of environmental contamination (Kazachonok and Popova, 2014). Radionuclides may end up in the food chain via contaminated ground water, contaminated soil or aerial deposition (Doyi et al., 2018).

For this hazard group, the literature search resulted in one paper on naturally occurring radionuclides in cassava from Ghana. During the advanced search in Google, no other relevant hits were obtained, and the additional search resulted in one relevant paper with occurrence data.

3.3.6.1 **Occurrence data**

In Ghana, 5 samples of cassava were tested for the radionuclides ^{238}U, ^{232}Th and ^{40}K. The samples were collected from a field close to the Tano Basin, which is rich in oil and gas. The following median concentrations were found: 0.64 Bq/kg for ^{238}U, 0.57 Bq/kg for ^{232}Th and 27.2 Bq/kg for ^{40}K. The authors concluded that ^{238}U had the highest mobility in the samples of cassava in this study, followed by ^{40}K and then ^{232}Th (Doyi et al., 2018).

The region Bryansk showed to contain 1.5-2.0 times higher radionuclide concentrations in vegetables from private gardens than in vegetables from collective farms as a result of the nuclear incident in Chernobyl (Kazachonok and Popova, 2014). In 2007, the vegetables beet, carrot and onion were sampled in the region of Chelyabinsk, where a nuclear facility is situated. Several nuclear incidents caused contamination with radionuclides in the environment. The samples were tested on the presence of ^{137}Cs and ^{90}Sr. The average concentrations of ^{137}Cs measured in beet, carrot and onion were 0.016 Bq/kg, 0.146 Bq/kg and 0.016 Bq/kg, respectively. For ^{90}Sr, the average concentrations were 0.026 Bq/kg in beet, 0.237 Bq/kg in carrot and 0.026 Bq/kg in onion. The highest values were reported in carrot, which were 4.86 Bq/kg for ^{137}Cs and 5.77 Bq/kg for ^{90}Sr. Although all concentrations found in the samples from these contaminated areas were the highest found in literature, the authors concluded that also these concentrations did not exceed the legal maximum levels (Kazachonok and Popova, 2014). According to Regulation (Euratom) No 2016/52, the maximum permitted levels (MPLs) of radioactive contamination of food (except infant food, dairy produce and liquid food) are 750 Bq/kg for ^{90}Sr and 1250 Bq/kg for ^{137}Cs.

3.3.6.2 **Conclusion**

Vegetables grown in areas contaminated due to nuclear incidents showed higher levels of radionuclides compared to other regions. However, concentrations found were below the EU MPLs.

3.3.7 Plant Protection Products (PPPs)/Pesticides

The literature study resulted in 12 relevant papers on pesticide residues in underground vegetables. Amongst these, 7 papers were included in the report. Some of the relevant papers were not included, due to the fact that the tested food product was not imported into the Netherlands in 2017 according to the Eurostat import data. Besides those, an evaluation of the 5 most recent pesticide reports from EFSA has been included in this section.

3.3.7.1 **Uptake in bulbs, root, stem and tuber vegetables**

Plant protection products (PPPs) are used in agriculture for the purpose of protecting food crops. At time of harvest, residues of the PPPs may still be present in the crops. The presence of these residual PPPs is extensively tested, amongst others by authorities (FAO, 2018; EFSA, 2019a).

Létondor and colleagues (2015) assessed the presence of chlordecone, which is banned for use in the EU, in the root vegetable radish. A concentration of 0.1 mg/kg chlordecone was found in the edible part of the plant. According to their work, the high chlordecone residue concentrations found can be ascribed to the chlordecone uptake, the thickness of the peel and the ratio between the surface of the peel and the volume of the flesh of the vegetables (Létondor et al., 2015).

In the pesticide reports of the FAO, data is given on the residues of pesticides in supervised trials. Residual concentrations in food crops were measured when pesticides are applied to the crops according to GAP (Good Agricultural Practices). In the report of 2017, all the pesticide residues found in underground vegetables, i.e. azoxystrobin, cyprodonil, fluopyram, flupyradifurone, chlorfenapyr and cyzofamid, were below the EU MRLs. Mean concentrations of azoxystrobin were 0.01 mg/kg in asparagus, 0.23 mg/kg in beetroot, carrot, celeriac, garlic, green onion, horseradish, Japanese radish, Jerusalem artichokes, parsnip, radish, salsify, swede, tannia, taro, turnip, yam, 1.2 mg/kg in kohlrabi and 2.2 mg/kg in other bulb vegetables (not specified which vegetables). For the residues of cyprodonil, mean concentrations were 0.195 mg/kg in carrot, 0.065 mg/kg in green onion and onion, 0.09 mg/kg in parsnip and 0.01 mg/kg in radish. Mean concentrations of difenoconazole were observed in asparagus with 0.02 mg/kg, in carrot with 0.05 mg/kg, in green onion with 2.8 mg/kg, in leek with 0.08 mg/kg and in onion with 0.015 mg/kg. Residues of the pesticide fluopyram were not detected in asparagus, but in carrot with 0.09 mg/kg, in garlic, leek, onion with 0.01 mg/kg and in green onion with 5.1 mg/kg. Mean concentrations of flupyradifurone were 0.18 mg/kg in the food group bulb vegetables, 0.29 mg/kg in the food group root and tuber vegetables and 0.291 mg/kg in sweet potato (FAO, 2017). In 2018, residues of chlorfenapyr in garlic and onion were below the level of quantification. Residues of cyzofamid were found in concentrations ranging from 0.032 mg/kg to 0.86 mg/kg in onion, from 0.46 mg/kg to 1.1 mg/kg in spring onion and from 1.1 mg/kg to 3.3 mg/kg in chives. In the latter, the metabolite CCIM of the pesticide cyzofamid was found in concentrations up to 0.2 mg/kg. The ARfD for this metabolite is 0.2 mg/kg bw. FAO concluded that it is unlikely that such quantities of chives are consumed that exceedance of the ARfD would occur (70 kg of chives are needed for exceedance of ARfD for an EU adult bw=70 kg). Therefore, no risks are identified for the dietary intake of these pesticides tested in the supervised trials (FAO, 2018).

3.3.7.2 **Occurrence data**

Chinese samples of <u>bamboo shoots</u> (n=27) were tested on the PPPs hexachlorocyclohexane (HCH), 1,1,1-trichlor-2,2-bis-(p-chlorophenyl) ethane (DDT) and pentachloronitrobenzene (PCNB). The average concentrations detected were 13 µg/kg, 31.1 µg/kg and 0.9 µg/kg fw, respectively. The Chinese MRL of 0.05 mg/kg is not exceeded by these concentrations, except for the concentration of PCNB that would exceed the Chinese MRL. The average value of both HCH and PCNB in the bamboo shoots would exceed the EU MRL (Guo et al., 2011).

In a Chinese survey on <u>sweet potatoes</u>, which were sampled in 2015, the presence of the PPPs dimethoate and omethoate was tested. Residues found in the vegetables were below the level of quantification, which is 0.02 mg/kg for dimethoate and 0.01 mg/kg omethoate. The hazard quotient (EDI dividing by ADI) was 0.016 for an adult (bw=60kg) and 0.033 for a toddler (bw=13kg) for dimethoate in <u>sweet potato</u> and 0.05 for an adult and 0.11 for a toddler for omethoate in <u>sweet potato</u>. The authors concluded that residues of these PPPs do not pose a risk to human health for the Chinese consumer, since all risk quotients were below 1 (Chen et al., 2018).

Another Chinese survey tested the PPP group pyrethrins in <u>turnips</u> sampled in 2016. Both <u>turnips</u> grown in open field and in green house showed lower levels than the EU MRL of 1 mg/kg for pyrethrins. With the help of the hazard quotient (HQ = EDI/ADI*100%) and an acute hazard index (aHI = estimated short term daily intake/ ARfD*100%), a risk assessment was performed for the long term and short term, respectively. Hereafter, the authors concluded that pyrethrins residues would not pose a risk to human health, since the HQ (0.37%) and aHI (0.41%) were below 100%, which indicate that there is no concern to human health (Feng et al., 2018).

In Thailand, from which ginger(products) is imported into The Netherlands, 119 samples of <u>ginger</u> were collected between 2005-2008. These samples were tested on the presence of 38 pesticides. In all samples tested, the pesticide residues were below the level of quantification (FAO, 2011).

On a local market in Ghent, Belgium, 30 samples of <u>yam</u> were collected in the period June-July 2016. Traces of the PPP fenpropimorph in all of these samples were detected with a median concentration of 0.13 µg/kg, cadusafos with 0.9 µg/kg and fenitrotion with 3.2 µg/kg. Thirteen samples showed residues of propiconazole with a median concentration of <0.1 µg/kg. Residues of propoxur and metaxyl occurred in seven samples of yam in median concentrations of 0.5 µg/kg and 0.3 µg/kg, respectively. In one sample, a concentration of 0.4 carbendazim µg/kg was detected. Notably, these concentrations are all well below the EU MRLs, which range between 0.01 mg/kg and 0.1 mg/kg (Wumbei et al., 2018).

EFSA yearly publishes the results of the EU Member States pesticides monitoring program. Results of the reports published in the last five years are summarised hereafter.

In the EU report on pesticide residues in food in 2013, leek was subject to a risk assessment by EFSA. In total, results of pesticide monitoring of 837 samples were gathered. The most frequently detected pesticides in these samples were boscalid, azoxystrobin, dithiocarbamates, pyraclostrobin and tebuconazole. None of these residues exceeded the MRL. Only 0.4% of leek samples exceeded the MRL. The exceedances were related to the pesticides fenbutatin oxide in one sample from Cyprus, pendimethalin in one sample from Portugal and zoxamide in one sample from France. Exceedances of the ARfD were calculated for some residues found in leek. The contribution to this HBGV was 113% for dithiocarbamates-maneb, 118% for chlorpyrifos, 234% for dithiocarbamates-propineb, 309% for dithiocarbamates-ziram. EFSA clarifies that the dietary exposure may have been overestimated, which gives an overestimation of the health risk (EFSA, 2015). Samples of leek (n=909) were also assessed for the EU pesticide report of 2016. Out of these samples, 1.2% were not compliant to the EU MRL. MRL exceedances were mainly found for the pesticide chlorpyrifos, followed by iprodione. Although the pesticides dithiocarbamates, tebuconazole, boscalid, azoxystrobin, difenoconazole were detected most frequently among the leek samples; the highest number of MRL exceedances were found for chlorpyrifos (<1.2% of leek samples). According to EFSA, the concentrations of chlorpyrifos found in leek would contribute with 1592% to the ARfD. This was 236% for dithiocarbamates-thiram, 178% for methiocarb, 147% for dithiocarbamates-ziram and 111% dithiocarbamates-propineb. The high concentrations of dithiocarbamates found may be due to background concentrations in the environment rather than due to the application as a PPP (EFSA, 2018a).

In 2014, 1256 monitoring data of carrots were gathered. MRL exceedances were observed in 0.7% of the cases. The pesticide residues mainly found in carrot samples were boscalid, linuron, azoxystrobin and difenoconazole. However, the highest number of MRL exceedances was with the pesticide chlorpyrifos (<1%) (EFSA, 2016a). In 2015, boscalid, azoxystrobin, difenoconazole, linuron and tebuconazole were also most frequently detected in carrots with the highest percentage of MRL exceedances for chlorpyrifos (<0.5%). For chlorpyrifos, concentrations found in 12 samples of carrot would result in an exceedance of the ARfD (EFSA, 2017a).

In 2015, turnip was one of the underground vegetable with the most MRL exceedances. Out of 116 turnip samples, 12.9% exceeded the MRL. Other underground vegetables with MRL exceedances (not specified which pesticides) were ginger (9.7% of 113 samples), spring onion (7.3% of 218 samples), cassava (5.8% of 86 samples), fennel (5.6% of 180 samples), celeriac (4.6% of 348 samples) (EFSA, 2017a). The 2017 pesticide residue report showed that chives (n=87) was one of the food products with the highest MRL exceedances (12.6% of the samples). This was followed by cassava (10.5%), turnip (9.3%), kohlrabi (7.4%), florence fennel (7.3%), celeriac (6.1%), ginger (6.1%) and carrot (0.8%). Samples of beetroot (n=18) were all below the MRL and 16 samples were below the LOQ. Except for 7.8%, almost all 1,013 onion samples were below the LOQ. For the onion samples with quantifiable residues, no non-compliances with MRLs were detected. Besides, none of the onion samples were exceeding an ARfD (EFSA, 2019a).

3.3.7.3 **Conclusion**

The occurrence data found showed that the average concentrations of the PPP HCH and PCNB found in bamboo shoots from China would exceed the EU MRL. Food products from the European market are sampled yearly on the presence of pesticide residues. In 2013, the monitoring results for dithiocarbamates (-maneb, -proneb, -ziram) and chlorpyrifos would result in an exceedance of the ARfD with the consumption of leek. In the last 5 years, MRL exceedances in leek and carrots were detected for chlorpyrifos, and the residues of this pesticides would also result in an exceedance the ARfD. Residues of dithiocarbamates (-propineb, -thiram, -ziram) and methiocarb would result in an exceedance of the ARfD with the consumption of leek. Dithiocarbamates were one of the pesticides, which were most frequently detected in leek. Other frequently found pesticides in leek were pyraclostrobin, tebuconazole and difenoconazole. The latter pesticide was also frequently detected in carrot, so were the pesticides azoxystrobin, boscalid and linuron. The samples from 2017 would not lead to the exceedance of the ARfD.

3.3.8 Mycotoxins

A summary of results found on uptake and occurrence of mycotoxins in underground vegetables is described below. One paper described the effect of processing on the presence of mycotoxins in cassava. This information was also included below.

3.3.8.1 **Uptake in in bulbs, root, stem and tuber vegetables**

Several fungi have the capability to produce mycotoxins, also in underground vegetables. Supporting circumstances for the fungi, like an environment with high moisture content, can lead to a rise of mycotoxin production (Abass et al., 2017).

Two experimental studies described the potential of fungi to produce mycotoxins in underground vegetables. The behaviour of *Fusarium* spp. and the potential of mycotoxin production were studied in asparagus by Waśkiewicz et al. (2013). After inoculation with different isolates of the fungi, the presence of ergosterol, fumonisin B1 and moniliformin was determined in asparagus. For the mycotoxin ergosterol, mean concentrations ranged between 10.6 µg/kg to 79 µg/kg. Moniliformin showed a range of mean concentrations between 1031 µg/kg and 6147 µg/kg. However, there are no legal limits for ergosterol and moniliformin. Mean concentrations of fumonisin B1 ranged from 28.5 µg/kg to 234.4 µg/kg. Notably, mycotoxins were found even in asparagus without visible symptoms of fungal growth. This could indicate that there is a possible uptake of mycotoxins from the soil into the asparagus (Waśkiewicz et al., 2013).The fungus *Fusarium proliferatum* often causes rot in garlic production in Spain. Seventy-nine *F. proliferatum* isolated from garlic bulbs were tested on their ability to produce mycotoxins, such as fumonisin B1, fumonisin B2, fumonisin B3, beauvericin and moniliformin by culturing them in rice medium. Minimum and maximum concentrations found for fumonisin B1, fumonisin B2 and fumonisin B3 were respectively 21 µg/kg and 9309.3 mg/kg, 13 µg/kg and 1329.9 mg/kg, non-detectable and 151.6 mg/kg. Beauvericin was not produced by 9 isolates, although one of the isolates produced a high concentration of 995.4 mg/kg. The mycotoxin moniliformin had the highest concentration of 99.2 mg/kg and was not produced by 12 isolates. Fumonisin B1 was the most abundant mycotoxin during this study. It should be noted that the ability to produce mycotoxins was tested in rice medium rather than on garlic bulbs (Galvez et al., 2017).

3.3.8.2 **Occurrence data**

Mayer and colleagues (2016) performed a study on the presence of several mycotoxins in onions, not specifically with regards to dietary exposure, but for occupational exposure during the sorting of onions in Germany, Italy and New Zealand. During this study, 3 out of 12 samples showed deoxynivalenol (DON) concentrations of 126 µg/kg and 136 µg/kg in onions from Germany and 587 µg/kg in an onion sample from Italy. For fumonisin B1, one sample contained 3940 µg/kg, which originated from Italy. Concentrations of fumonisin B2 were 55 µg/kg (from Germany), 90 µg/kg (origin unknown), 485 µg/kg (from Italy) and 554 µg/kg (from Germany). Other mycotoxins, such as beauvericin, enniatin A, enniatin A1, enniatin B and enniatin B1 were also found, but these concentrations were all below the LOQ (Mayer et al., 2016).

The values of aflatoxins and ochratoxin were compared in Nigerian ginger, harvested in the dry season (n=89) and the rainy season (n=31). Mean concentrations measured in the dry season samples were 0.46 µg/kg, 0.09 µg/kg and 1.02 µg/kg for aflatoxin B1, B2 and ochratoxin A, respectively. For the rainy season samples, mean concentrations were 2.32 µg/kg, 0.21 µg/kg and 3.94 µg/kg for aflatoxin B1, B2 and ochratoxin A, respectively. Both aflatoxin G1 and G2 were not detected in this study. From the samples collected in the rainy season, the concentration of aflatoxin B1 in 23% of the samples surpassed the EU maximum level (ML) of 5.0 µg/kg for aflatoxin B1 in ginger. For ochratoxin A, none of the samples had concentrations exceeding the EU ML. During the rainy season, 65% of the samples contained both aflatoxins and ochratoxin A. This percentage was 21% for the samples collected in the dry season. It can be concluded from this study that there is seasonal variation in the presence of mycotoxins in ginger and that both the prevalence of mycotoxins and the concentrations in the samples of the rainy season contained higher concentrations than the dry season (Lippolis et al., 2017).

In a survey during 2005-2007, cassava from the Ivory Coast was tested on the presence of aflatoxins, deoxynivalenol and ochratoxin A. Only for the latter mycotoxin, concentrations were detected. The maximum ochratoxin A concentration found in this study was 0.2 µg/kg (Kastner et al., 2010). In Guyana, 40 samples of cassava flour and 40 samples of cassava bread were tested on the presence of aflatoxin B1, B2, G1 and G2. None of the samples contained aflatoxins (Morrison et al., 2019). Also Ofori and colleagues did not detect aflatoxins in fresh nor processed cassava samples (Ofori et al., 2016). A study in Uganda evaluated the presence of aflatoxins in cassava crisps and found that low aflatoxin concentrations were found in over a quarter of all samples; the highest concentration of all samples was 4.5 µg/kg (Kaaya and Eboku, 2010). Manjula et al. (2009) studied the presence of aflatoxins and fumonisins in crisps and flour made from both maize and cassava. In the processed cassava samples (cassava crisps and cassava flour), concentrations of aflatoxin B1 ranged from 0.3 to 4.4 µg/kg. When unprocessed cassava was stored, aflatoxin concentrations increased up to 34 µg/kg after 4 months. The fumonisin concentrations ranged from not-detectable to 70 µg/kg. All in all, maize showed higher mycotoxin concentrations than cassava in this study (Manjula et al., 2009). In Rwanda, 15 samples of cassava flour were tested for the presence of aflatoxin B1, B2, G1 and G2. Aflatoxin concentrations found were all below the LOD of 0.15 µg/kg (Matsiko et al., 2017). FAO reported mycotoxin levels in cassava. Import data showed that relevant countries for this research were Cameroon and Nigeria, from which cassava is imported into The Netherlands (see section 3.1). One out of 8 samples of fresh cassava from Cameroon contained 0.65 µg/kg ochratoxin A, 2.4 µg/kg alternariolmethylether and 0.3 µg/kg methylsulochrin. Two samples out of 8 contained 0.07 µg/kg and 0.21 µg/kg for quinolactacin A. Concentrations for the mycotoxins integracin A, integracin B and methylfunicone were found in fresh cassava from Nigeria to be 0.49 µg/kg, 0.91 µg/kg and 0.51 µg/kg, respectively. These mycotoxins were all detected in one of the 8 samples. Cassava crisps from Cameroon and Nigeria were tested for the content of total aflatoxins. Concentrations ranged between 5.2 µg/kg and 14.5 µg/kg for total aflatoxins in 72 samples of cassava crisps from Cameroon. Three samples out of the 4 cassava crisps samples from Nigeria each showed a detectable concentration of total aflatoxins of 0.07 µg/kg (FAO, 2019).

3.3.8.3 **Effects of processing**

A Nigerian study found that fresh cassava contains significantly higher mycotoxin levels than cassava crisps and this is most likely due to the high moisture content in fresh cassava, which supports mould growth. The cassava for cassava crisps are processed after harvest and are barely stored in between. Fresh cassava is stored for a longer time, which allows the fungi to grow (Abass et al., 2017).

3.3.8.4 **Conclusion**

Experimental studies showed that *Fusarium* spp. are capable to produce a range of mycotoxins in asparagus and garlic. Furthermore, occurrence data showed that aflatoxin concentrations up to 34 µg/kg can be found in stored fresh cassava samples and in ginger, concentrations found exceeded the EU ML.

3.3.9 Plant toxins

The collective name of secondary metabolites in plants, which have toxicological properties, is plant toxins. Hydrocyanic acid (HCN) is one of these secondary plant metabolites and is highly toxic to humans. HCN appears when cyanogenic glycosides, such as linamarin and lotaustralin, are hydrolysed (FAO, 2019). Plant toxins can be present in underground vegetables; however, literature study has shown that data is mainly reported on HCN in cassava. The literature search resulted in six relevant papers on this hazard group, of which five concerned HCN in cassava. One paper described the effect of processing of HCN content in bamboo shoots. Another two reports on HCN in cassava were obtained by the advanced search in Google. The additional search did not retrieve information on other plant toxins.

3.3.9.1 Occurrence data

Cassava contains the cyanogenic glycosides linamarin and lotaustralin, which may be converted by the naturally present linamarase into HCN. The FAO is currently discussing the establishment of maximum levels for HCN in cassava and products thereof. For this purpose, monitoring data on the presence of these precursors is gathered. The cyanogenic glycoside linamarin was found in concentrations up to 19.8 mg/kg in fresh cassava from Cameroon. The highest concentration found for the cyanogenic glycoside lotaustralin was 13.0 mg/kg, which was also detected in fresh cassava from Cameroon (FAO, 2019). In an earlier report from the FAO on maximum levels for HCN in cassava and products thereof in 2013, occurrence data on HCN were reported. Fresh cassava coming from Australia had a mean concentration of 27 mg/kg, which was 55.8 mg/kg in cassava crisps from Australia. Mean concentrations were 100.3 mg/kg and 19 mg/kg for fresh cassava coming from Ghana and Indonesia, respectively. In samples from Nigeria, the mean concentrations were 105 mg/kg and 103 mg/kg for sweet, fresh cassava and bitter, fresh cassava, respectively. Cassava from Brazil and Cameroon contained concentrations as high as 26-451 mg/kg and 197-951 mg/kg. These were the highest ranges of HCN concentrations measured in cassava from these countries. The results showed that many cassava products exceeded the maximum level of 10 mg/kg as it is applied in Australia and New Zealand. Consumption of samples of both fresh cassava and cassava crisps could exceed the ARfD (0.09 mg/kg bw) in adults (FAO, 2013). A survey in 2008 of cassava crisps available on the Australian market, revealed that only 15% of the 374 samples taken were below the Australian ML of 10 mg/kg HCN. The mean concentration was found to be 64.2 mg/kg. The authors stressed that young children are at risk when consuming 100 g of cassava crisps with a HCN concentration of 10 mg/kg (Miles et al., 2011). Authors from another survey in Nigeria also showed their concerns with regard to the consumption of cassava and/or cassava products and the exposure to HCN. They measured the potential of HCN production in different species of cassava. The highest concentrations had a mean of 1014 mg/kg FW in the species named TMS 01/1368. Lower values were observed in cassava flour (highest mean concentration: 22.1 mg/kg) than in cassava crisps (7.2 mg/kg) (Ekere and Eze, 2014).

Due to the high acute toxicity of HCN, EFSA has set an ARfD of 0.02 mg/kg body weight per day (EFSA, 2016b). However, no maximum level has been set for cassava in Regulation (EC) No 1881/2006.

3.3.9.2 Effects of processing

According to Mombo et al. (2017) soaking cassava for 18-24 hours prior to consumption can diminish the content of HCN. The most effective method according to Nambisan (2011) is grating, followed by dewatering and drying of cassava. Bradbury et al. (2011) promotes this method as well and indicates that it reduces the total cyanide content in the end product 3-6 fold.

In 2016, Devi et al. (2017) studied the HCN concentration in bamboo shoots and the effect of different preparation methods thereon. The fresh bamboo shoot contained 600 mg/kg of HCN. The traditional preparations of bamboo shoots considered in this study were bamboo curry, bamboo salad, fried bamboo, bamboo pickles, bamboo chutney and fermented bamboo. Results of the study showed that the content of HCN in bamboo was halved after 2 hours of soaking. Boiling dropped the HCN content from approximately 300 to 100 mg/kg after 15 minutes. Fermentation took 4 months to reduce the HCN from approximately 280 to 175 mg/kg. As a result, the authors concluded that bamboo shoot salad was the most effective preparation to reduce the HCN content. This can be ascribed to the fact that the salad making consists of several preparation steps, like soaking, pressure cooking and squeezing (Devi et al., 2017).

3.3.9.3 Conclusion

The literature review showed that cassava crisps may surpass the ML of Australia and New Zealand for HCN (10 mg/kg). Food preparation can mitigate the presence of HCN, like soaking cassava prior to consumption lowers the HCN content in the final product. Indeed, a survey in Nigeria showed that levels in fresh cassava were higher than in crisps and flour.

3.3.10 Processing contaminants

Processing can help to make food more digestible and it can mitigate food hazards. Nevertheless, new hazards may also be introduced. An example thereof is acrylamide, which is formed after heating of starchy products. These types of hazards are called processing contaminants.

Three relevant papers described the concentrations found of several processing contaminants in underground vegetables. The data on benzene was retrieved during the literature review and data on the other two contaminants were obtained during the advanced search in Google.

Together with the product group cereals, tuber vegetables are the main contributors to the dietary exposure to acrylamide. Nevertheless, this is especially true for potato, which is out of scope for this research (for more information, see (Nijkamp et al., 2017)). Besides potatoes, other tuber vegetables are processed into crisps and thus heated. Mean concentrations in samples of pan-fried asparagus, beetroot, carrots, onions and baked cassava were found to be 100 μg/kg, 15 μg/kg, 31 μg/kg, 61 μg/kg and 100 μg/kg, respectively. The contribution of cassava to the total intake of acrylamide is calculated to be 9.9% for the highest consumption rates. For cluster diet E (the North-Western European diet), the contribution to the total dietary acrylamide intake was 0% for cassava, asparagus and beetroot, 0.3% for carrots and 0.5% for onions. Dietary intakes of acrylamide through the consumption of root and tuber vegetables was estimated to be between 0.2 and 2.2 μg/kg bw/d for the global population, with processed potato as the main contributor (WHO and FAO, 2011).

Furan can be regarded as another processing contaminant. A limited number of samples were analysed for the presence of furan in asparagus (n=4), bamboo shoot (n=2), beets (n=4) and carrots (n=5). The mean concentrations in these samples were 5.5 μg/kg, 2.1 μg/kg, 100.4 μg/kg and 43.9 μg/kg, respectively. Underground vegetables were not regarded as high contributors to the intake of furan. FAO concluded that the risk of contaminating the food product with furan can be mitigated by heating in an open pan while stirring. Still, there is a lack of knowledge on the mitigation of furan contamination and a lack of quantitative data of furan in all sorts of food products (WHO and FAO, 2011).

Benzene is carcinogenic and smoking and driving are contributing to the exposure of this carcinogen. However, high benzene levels are also reported in children and non-smokers. Lachenmeier et al. (2010) hypothesised another route of exposure for these population groups. Several processed infant foods, containing carrot, were tested on the content of benzene and this was compared to similar products freshly made at home. The latter did not contain benzene, but in the processed carrot foodstuffs benzene levels were detected. The author indicated that a natural compound in carrots, such as amino acids, carotenoids or terpenes may act as a precursor of benzene, which is converted by heat treatment. The survey included 8 cans of carrots in brine, 8 cans of carrots without brine, 10 jars of carrots in brine and 10 jars of carrots without brine and mean concentrations were found to be 0.29, 0.17, 0.48, 0.31 μg/kg, respectively. Based on German consumption data, these concentrations will not lead to an exceedance of the RfD of 4 μg/kg bw/d, as set by the US EPA (Lachenmeier et al., 2010).

3.3.10.1 **Conclusion**

Food preparation can mitigate the presence of hazards, but it can also introduce new hazards in the food products. Three papers described concentrations of the processing contaminants acrylamide, benzene and furan in processed underground vegetables. The underground vegetables that were studied in this research were not the main contributors to the dietary intake of the compounds acrylamide and furan.

3.3.11 Processing aids and food additives

Both the literature study and the advanced search in Google did not result in relevant hits for this class of hazards. By performing an additional search for this class of hazards, no relevant hits are retrieved.

Processing aids and additives are intentionally added to improve the quality of food products. Whereas food additives are ingredients that will be present in the finished product, processing aids are in place to improve processing of the food product and are not meant to be present in the finished product. Processing aids and food additives are subject to pre-market approval. Assessments have to show that these substances do not pose a risk to human health before they can enter the EU market (Regulation (EC) No 1331/2008.

3.3.12 Cleaning agents and disinfectants

Cleaning agents can be present in waste water because they are widely used. By the use of treated waste water for irrigation of food crops, cleaning agents may enter the food chain (Aparicio et al., 2018). To date anno 2020, this is not allowed in the Netherlands. Notwithstanding, evolving trends towards circular economy can lead to the allowance of the reuse of treated waste water in the future (European_Commission, 2018b, 2018a). In other EU countries, such as Cyprus, treated wastewater is being used for irrigation (European_Commission, 2016). Crops imported from these countries may thus contain residues of cleaning agents. Furthermore, cleaning agents and disinfectants are used during processing of vegetables and residues may end up in the final product.

Only one study found in the literature search, provided occurrence data on cleaning agents and disinfectants. Furthermore, BfR reported monitoring data on some cleaning agents and disinfectants. This data was retrieved during the advanced search in Google.

After conducting a risk assessment, BfR concluded that raising the EU maximum residue limit (MRL) (being 0.01 mg/kg as default EU MRL at that time) for <u>didecyldimethylammonium chloride (DDAC)</u> is reasonable. Considering an ADI of 0.1 mg/kg bw/day and an ARfD of 0.1 mg/kg bw, BfR declared that the exposure of DDAC as reported in food samples is unlikely to pose a risk for the German or European consumer. All samples of root and tuber vegetables (n=29) were below the level of quantification and one sample out of 38 stem vegetables was quantifiable with a concentration of 0.029 mg/kg (BfR, 2012b). BfR also assessed <u>benzalkonium chloride (BAC),</u> to which the default EU MRL of 0.01 mg/kg applied at that time. Again, no root and tuber vegetables (n=29) contained a quantifiable concentration. For the stem vegetables (classification, see Annex 3), 38 samples were analysed for BAC showing that one concentration of 0.01 mg/kg was found, the others were unquantifiable. An ADI value of 0.1 mg/kg body weight and an ARfD of 0.1 mg/kg body weight were used for BAC. Considering that one kilogram of only 1 sample of stem vegetables would contribute 10% to the HBGVs of 0.1 mg/kg body weight, the BfR expressed that it is unlikely that BAC would pose a risk to human health with the current residue levels in food (BfR, 2012a). The EU MRL has been increased to 0.1 mg/kg in 2014 (European_Commission, 2014).

Aparicio et al. (2018) analysed the presence of surfactants in <u>carrot</u> (n=4) and <u>turnip</u> (n=4). The surfactants tested in this study were nonylphenol (NP), nonylphenol ethoxylates for the ionic surfactants and alkylsulfates (AS) and linear alkylbenzene sulfonates (LAS) for the anionic surfactants. For the surfactant nonylphenol, mean concentrations measured were 22.9 μg/kg in carrots and 9.3 μg/kg in turnip. This surfactant was found to be the highest contaminant amongst all surfactants tested in this study. The mean concentrations of AS in carrots ranged between 3.1 μg/kg and 7.9 μg/kg and in turnip between 0.4 μg/kg and 2.9 μg/kg. The mean LAS concentration ranged between 1.4 μg/kg and 15.8 μg/kg for carrots and between 1.3 μg/kg and 7.6 μg/kg in turnip. Aparicio et al. (2018) estimated the daily intake of LAS based on a 300 gram consumption and worst-case concentrations which resulted in an EDI of 4.7 μg/d. However, there are no HBGV to compare this EDI with (Aparicio et al., 2018).

3.3.12.1 **Conclusion**
DDAC and BAC were not detected in root and tuber vegetables and detected in negligible concentrations in stem vegetables in a survey conducted by BfR. One study showed that residues of surfactants may be present in carrots in turnips. However, there are no legal limits or HBGVs for these compounds.

3.3.13 Other chemical hazards

During the literature search, two experimental studies on the uptake of nanoparticles and one paper indicating occurrence data on cyanobacterial toxins were retrieved. The advanced search in Google resulted in one document on the occurrence of phthalates in root vegetables and two documents on the presence of perchlorate in carrots.

3.3.13.1 **Uptake in bulbs, root, stem and tuber vegetables**

In this literature study, 2 experimental studies were found that investigated nanoparticles in underground vegetables. In a study on radish, nanoparticles of cerium dioxide were added to the soil in doses of 10 mg/kg, 50 mg/kg and 100 mg/kg and no cerium dioxide was added in the control soil. For all the different soils with amendments, concentrations of cerium dioxide were below 2.5 mg/kg in the leaf of the radish plant. In the roots, concentrations of cerium dioxide were 9 mg/kg for the control, 12 mg/kg for dose 1, 15 mg/kg for dose 2 and 23 mg/kg for dose 3. This shows that cerium dioxide in the soil is taken up by the roots and especially accumulates in the roots and is not translocated to further plant parts (Gui et al., 2017). Another experiment, investigated the growth and the uptake of Ce, Cu and Zn and their nanoparticles ($nCeO_2$, nCuO and nZnO) in sweet potato. The metals and their nanoparticles were amended to the growth substrate in concentrations of 100 mg/kg dw, 500 mg/kg dw and 1000 mg/kg dw. The growth substrate without any metal amendment functioned as control. Overall, the peels of the sweet potato showed higher concentrations than the flesh. The difference was largest for Ce and its nanoparticles and smallest for Zn and its nanoparticles. Barely any difference was noticed in the metal concentration of the ion samples or the nanoparticle samples. Except for Ce, for which the metal concentrations in the nanoparticle samples were higher than the ion samples, especially in the peel. The concentrations of Ce, Cu and Zn in the unpeeled control samples were <0.5 mg/kg dw, <4 mg/kg dw and <10 mg/kg dw, respectively. For Ce, the highest concentration of all samples was observed in the peel with the amendment of 500 mg/kg dw $nCeO_2$, which was approximately 12.5 mg/kg dw. The highest concentration found in unpeeled samples was <5 mg/kg dw in the sample amended with 1000 mg/kg dw $nCeO_2$. For Cu, the highest concentrations in the peeled and unpeeled samples were observed for soils amended with 1000 mg/kg dw of nCuO. The concentration in the peel was approximately 60 mg/kg dw and approximately 22 mg/kg in the unpeeled samples. The unpeeled sample with amendment of 1000 mg/kg Zn (ion) had the highest Zn concentration with approximately 130 mg/kg dw. The peel samples showed the highest concentration of approximately 170 mg/kg dw after treatment with 1000 mg/kg dw nZnO. The authors concluded that nanoparticles of these metals will not pose a risk to the yield of the food crop, nor to the food safety in comparison to the ions (Bradfield et al., 2017).

3.3.13.2 **Occurrence data**

Cyanobacterial toxins, such as microcystins, were reported in water chestnuts. A small survey of 24 samples in 2007 in China found that 6 samples collected in the Lake Tai contained this toxin. The concentrations ranged from 1.12 to 7.02 μg/kg. All 6 samples collected at the market in Wuxi did not contain microcystins. The study demonstrated that water chestnut has the potential to accumulate this toxin. The highest concentration found would lead to an exceedance of the WHO TDI (0.04 μg/kg) in case 1429 g fresh water chestnuts are consumed (Xiao et al., 2009).

Phthalates, such as bis(2-ethylhexyl) phthalate (DEHP), diisononyl phthalate (DiNP) and diisodecyl phthalate (DiDP) are chemical compounds present in plastic materials. A study in the UK previously considered food products from animal origin for the exposure estimation for humans of phthalates in food. Another assessment in Denmark also considered food products from non-animal origin, such as fruit and vegetables. Although the median was calculated to be non-detectable, a maximum concentration of the plasticiser DEHP was found to be 1.4 mg/kg fw in the food group of fruit and vegetables. It was estimated that the food group of root vegetables contributed 13% to the dietary exposure of these plasticisers (FAVV, 2014b).

Perchlorate can end up in vegetables via the soil, (irrigation) water or due to the use of fertilisers containing sodium nitrate obtained from environments rich in perchlorate (FAVV, 2013). The Joint FAO/WHO Expert Committee on Food Additives (JECFA) in 2011 reported an average perchlorate concentration in carrots of 6.6 μg/kg. FAVV used these data to compare to the perchlorate levels in leafy vegetables. This showed that the concentrations in leafy vegetables were higher than those found in carrots. The food group carrots appeared to be one of the food groups with the lowest perchlorate concentrations. Furthermore, the average perchlorate concentration in carrots is well below the provisional reference value of 200 µg/kg for perchlorate root and tuber vegetables (FAVV, 2013). BfR performed a health assessment on perchlorate levels. A survey was conducted in 2013 in which 118, 54, 52 of root, bulb and stem vegetables (classification, see Annex 3), respectively, were tested on the presence of perchlorate. Among these samples, 51% of the root vegetables were tested positively for perchlorate residues; this value was 4% for bulb vegetables and 21% for stem vegetables. With respect to the highest residue level detected, bulb vegetables contributed 12% to the PMTDI of perchlorate (0.01 mg/kg bw/day), stem vegetables for 55% and root vegetables contributed 1784%. For root vegetables, 16% of the samples would result in an exceedance of the ARfD (BfR, 2013).

3.3.13.3 **Conclusion**

Experimental studies showed that nanoparticles can be taken up from the soil into radish and sweet potatoes. However, they primarily accumulate in the non-edible parts of the plants. Cyanobacterial toxins were detected in approximately 20% of the water chestnut samples from China. The highest concentration found would lead to an exceedance of the TDI at a daily consumption of 1429 g. Phthalates detected in root vegetables would contribute 13% to the total intake of these compounds. The highest concentration found was 1.4 mg/kg fw for DEHP. Perchlorate was detected in several underground vegetables, but especially its presence in root vegetables would result in an exceedance of the ARfD.

3.4 Long list and intermediate list

Based on the literature review, the advanced search using Google and additional searches, a long list of chemical hazards that may occur in underground vegetables was established. This long list is depicted in Table 1. Those hazards that were frequently found in underground vegetables or were found at concentrations exceeding legal limits or resulting in an exceedance of HBGVs were included in a so-called intermediate list. Furthermore, in case underground vegetables were indicated as main contributors to the dietary intake of a compound, this compound was also included on the intermediate list. Table 1 also includes knowledge gaps for chemical hazards that were encountered in experimental studies, but for which occurrence data in underground vegetables on the market were lacking. Further research, e.g. a survey, is needed to establish the relevance of these hazards.

Table 1 *Long list and intermediate list of chemical hazards in underground vegetables.*

Long list ***Hazards that may occur in underground vegetables***	**Intermediate list** ***Hazards that are frequently found in underground vegetables, found above legal limits or that resulted in exceedance in HBGV***	**Knowledge gaps**	**Rationale for inclusion/exclusion on intermediate list**
Heavy metals and other elements (section 3.2.1)			
Aluminium (Al)	-	Al	Only one study reported the presence of Al in carrots. Levels were detected in conventional, organic and self-grown carrots (12.3 mg/kg, 18.5 mg/kg, 20.3 mg/kg, respectively).
Arsenic (As)	As		Multiple papers reported the presence of As in radish, lotus roots, asparagus, carrots. Concentrations of inorganic As in radish resulted in an exceedance of the PMTDI using Indian consumption data.
Cadmium (Cd)	Cd		Levels > EU ML were detected in asparagus, carrots and lotus roots.
Chromium (Cr)	-		The toxic compound Cr6+ rapidly degrades to Cr3+; levels of which were not found above Belgium action limits. An experimental study also did not show human health effects due to the presence of Cr in carrots.
Cobalt (Co)	-		Only 1 study reported the presence of Co in asparagus at concentrations of 0.05 and 0.1 mg/kg. According to Barceloux and Barceloux (1999), a daily intake < 37 mg/day would not result in adverse human health effects
Copper (Cu)	-		Cu is an essential element. According to EFSA, underground vegetables are not the main contributors to dietary intake (EFSA, 2018d).
Iron (Fe)	-		Fe is an essential element. The literature review showed that concentrations found would not lead to adverse health effects as reported by EFSA at 50-60 mg/day.
Lead (Pb)	Pb		Levels > EU ML were detected in lotus roots, asparagus and carrots. Concentrations found in cassava flour would lead to an exceedance of the BMDL based on Brazilian consumption data.
Nickel (Ni)	-		Levels found did not results in an exceedance of the TDI.
Zinc (Zn)	-		Levels found will not result in an exceedance of the UL.
Persistent organic pollutants (section 3.2.2)			
Perfluoroalkyl substances (PFAS)	-		According to EFSA (2018e), underground vegetables are not the main contributors to the PFOS and PFOA intake.

Long list *Hazards that may occur in underground vegetables*	Intermediate list *Hazards that are frequently found in underground vegetables, found above legal limits or that resulted in exceedance in HBGV*	Knowledge gaps	Rationale for inclusion/exclusion on intermediate list
Polycyclic Aromatic Hydrocarbons (section 3.2.3)			
PAH8	PAH8		A literature review revealed that levels may be high (> 5 μg/kg) when root vegetables are grown in urban or industrial areas.
Nitrate (section 3.3.4)			
Nitrate	Nitrate		Radish and beetroot can contribute more than 50% to the ADI for nitrate.
Pharmaceuticals and other chemical residues (section 3.2.5)			
Antibiotics (nitrofuran, triclosan, sulfamethoxazole, ciprofloxacin, norfloxacin, monensin, virginiamycin, tylosin, gentamycin, amoxicillin, enrofloxacin, florfenicol, oxytetracycline, sulfadiazine, trimethoprim, tylosin)			Experimental studies indicated a possible uptake in underground vegetables. However, there are no indications that HBGVs are exceeded for these substances.
NSAIDs (diclofenac, ibuprofen, ketoprofen, naproxen)			Experimental studies indicated a possible uptake in underground vegetables. However, there are no indications that HBGVs are exceeded for these substances.
Other pharmaceuticals (lamotrigine, caffeine, carbamazepine, bezafibrate, clofibric acid, gemfibrozil, metoprolol, sildenafil, triamterene, levamisole)		Lamotrigine, 10,11-epoxycarbamazepine (metabolite of carbamazepine)	According to Malchi et al. (2014), the TTC would be exceeded for lamotrigine and 10,11-epoxycarbamazepine with the concentrations found in the experimental study. However, no occurrence data on underground vegetables on the Dutch market were found.
Other chemical residues (DEET, ambrettolide, diazinon)			Experimental studies indicated a possible uptake in underground vegetables. However, there are no indications that HBGVs are exceeded for these substances.
Radionuclides (section 3.2.6)	-		
U^{238}	-		One study from Ghana showed the presence of U^{238} (n=5) at low concentrations (0.6 Bq/kg).
Th^{232}	-		One study from Ghana showed the presence of Th232 (n=5) at low concentrations (0.6 Bq/kg).
K^{40}	-		One study from Ghana showed the presence of K40 (n=5) at low concentrations (27 Bq/kg).
Cs^{137}	-		Levels < EU MPLs were detected.
Sr^{90}	-		Levels < EU MPLs were detected.

Long list *Hazards that may occur in underground vegetables*	Intermediate list *Hazards that are frequently found in underground vegetables, found above legal limits or that resulted in exceedance in HBGV*	Knowledge gaps	Rationale for inclusion/exclusion on intermediate list
PPPs (section 3.2.7)	-		
PPPs	Azoxystrobin		Most frequently detected in leek and carrots.
	Boscalid		Most frequently detected in leek and carrots
	Chlorpyrifos		Concentrations > EU MRL found in leek and carrots. ARfD is exceeded by the consumption of leek and carrots.
	Difenoconazole		Most frequently detected in leek and carrots.
	Dithiocarbamates (dithiocarbamate-maneb, dithiocarbamate-proneb, dithiocarbamates-thiram, dithiocarbamates-propineb, dithiocarbamate-ziram)		Most frequently detected in leek and ARfD is exceeded.
	Fenbutatin oxide		An MRL exceedance was found in leek.
	HCH		Concentrations > EU MRL found for bamboo shoots from China.
	Iprodione		Concentrations > EU MRL found in leek.
	Methiocarb		ARfD exceeded based on concentrations found in leek.
	Linuron		Most frequently detected in carrots.
	PCNB		Concentrations > EU MRL found for bamboo shoots from China.
	Pendimethalin		An MRL exceedance was found in leek.
	Pyraclostrobin		Most frequently detected in leek.
	Tebuconazole		Most frequently detected in leek.
	Zoxamide		An MRL exceedance was found in leek.
Mycotoxins (section 3.2.8)			
Aflatoxins	Aflatoxin B1		Concentrations of AFB1 exceeded the EU ML in ginger.
Alternariolmethylether (AME)	-		Detected in 1 out of 8 cassava samples from Cameroon.
Beauvericin	-		Concentrations found in onions were < LOQ.
Deoxynivalenol (DON)	-		Concentrations found in onions were low (126 μg/kg).
Enniatins	-		Concentrations found in onions were < LOQ.
Ergosterol	-		One experimental study showed that *Fusarium* spp can produce ergosterol in asparagus (11-79 μg/kg). This was not confirmed in occurrence studies.

Long list *Hazards that may occur in underground vegetables*	Intermediate list *Hazards that are frequently found in underground vegetables, found above legal limits or that resulted in exceedance in HBGV*	Knowledge gaps	Rationale for inclusion/exclusion on intermediate list
Fumonisins	Fumonisins		Studies showed that fumonisins can be formed in underground vegetables at high concentrations (up to 3940 µg FB1/kg in onion).
Integracins	-		Detected in 1 out of 8 fresh cassava samples from Nigeria at low concentrations (<1 µg/kg).
Methylfunicone	-		Detected in 1 out of 8 fresh cassava samples from Nigeria at low concentrations (<1 µg/kg).
Methylsulochrin	-		Detected in 1 out of 8 fresh cassava samples from Cameroon at low concentrations (<1 µg/kg).
Moniliformin		Moniliformin	Two experimental studies showed that Fusarium spp can produce moniliformin in asparagus up to 6 mg/kg and isolates from garlic produced concentrations up to 99 mg/kg. However, no occurrence data were found.
Ochratoxin A (OTA)	-		Concentrations found did not exceed the EU ML.
Quinolactacin A	-		Detected in 2 out of 8 fresh cassava samples from Cameroon at low concentrations (<1 µg/kg).
Plant toxins (section 3.2.9)			
Hydrocyanic acid (HCN)	HCN		Levels above the FSANZ ML (10 mg/kg) were detected in cassava and the ARfD is exceeded through consumption of cassava crisps.
Processing contaminants (section 3.2.10)			
Acrylamide	-		The tuber vegetables included in this study contribute <10% to the acrylamide intake.
Benzene	-		Levels found did not result in an exceedance of the US RfD.
Furan	-		Underground vegetables were not regarded the main contributors to furan dietary intake.
Processing aids & additives (section 3.2.11)			
-			
Cleaning agents and disinfectants (section 3.2.12)			
Benzalkonium chloride (BAC)	-		Levels found did not result in an exceedance of HBGVs.
Didecyldimethylammonium chloride (DDAC)	-		Levels found did not result in an exceedance of HBGVs.
Perchlorate	Perchlorate		Levels > EU MRL were detected in root vegetables.

Long list ***Hazards that may occur in underground vegetables***	**Intermediate list** ***Hazards that are frequently found in underground vegetables, found above legal limits or that resulted in exceedance in HBGV***	**Knowledge gaps**	**Rationale for inclusion/exclusion on intermediate list**
Surfactants (NP, AS, LAS)		Surfactants (NP, AS, LAS)	One paper analysed surfactants in 4 carrots and turnips. Due to a lack of HBGV, the established concentrations could not be evaluated on their relevance for human health.
Other chemical hazards (section 3.2.13)			
Phthalates (DEHP, DIDP, DiNP)	Phthalates		Levels found in root vegetables showed to contribute 13% to the dietary intake of phthalates.
Microcystins	-		The TDI may be exceeded at the highest concentration found in case 1429 g water chestnuts are consumer per day. For the Netherlands, these amounts are not likely to occur.
Nanoparticles	-		According to Bradfield et al. (2017) nanoparticles primarily accumulate in the non-edible part of radish (i.e. the roots).

3.5 Toxicological information

This section provides toxicological information of the prioritised hazards on the intermediate list and on the hazards identified as knowledge gap. This information is presented in Table 2, except for the prioritized pesticides, and includes information on the HBGVs and MLs. Furthermore, the main contributors to the dietary intake of these hazards are indicated in sections 3.5.1-3.5.12. The information was collected from EFSA and RIVM reports, which were available for aluminium, arsenic, cadmium, lead, PAHs, nitrate, aflatoxins, fumonisins, moniliformin, hydrocyanic acid, perchlorate and phthalates. For the prioritized pesticides, the relevant toxicological information, including MRLs, ARfDs and ADI's, and approvals, was collected from the EU pesticides database; this information is summarized in Table 3.

Table 2 *HBGVs and MLs for the prioritised hazards and hazards identified as knowledge gap.*

Prioritised hazards	EU ML[a] (mg/kg FW)	Chronic effect (µg/kg bw/day)	Acute effect (µg/kg bw)
Heavy metals and other elements (section 3.2.1)			
Aluminium	N[b]	TWI: 1000 (EFSA, 2008d).	N[b]
Arsenic (As)	N[b]	BMDL01: 0.3-8 (EFSA, 2014a)	N[b]
Cadmium (Cd)	0.2 (celeriac, horseradish, parsnip, salsify), 0.1 (other underground vegetables),	TWI: 2.5 (EFSA, 2009a)	N[b]
Lead (Pb)	0.3 (salsify), 0.1 (other underground vegetables)	$BMDL_{01}$: 0.5 (for young children) $BMDL_{01:}$ 1.5 (for cardiovascular effects in adults) $BMDL_{10:}$ 0.63 (for and nephrotoxicity in adults) (EFSA, 2012b)	N[b]
Polycyclic Aromatic Hydrocarbons (section 3.2.3)			
PAH8	N[b]	$BMDL_{10}$: 490 (EFSA, 2008c)	N[b]
Nitrate (section 3.3.4)			
Nitrate	N[b]	ADI: 3700 (EFSA, 2008a).	N[b]
Pharmaceuticals and other chemical residues (section 3.2.5)			
Lamotrigine,	N[b]	N[b]	N[b]
10,11-epoxycarbamazepine (metabolite of carbamazepine)	N[b]	N[b]	N[b]
Mycotoxins (section 3.2.8) µg/kg			
Aflatoxin B1	5.0 (ginger)	NA, genotoxic carcinogen	N[b]
Fumonisins	N[b]	TDI: 1 (EFSA, 2018b)	N[b]
Moniliformin	N[b]	N[b]	N[b]
Plant toxins (section 3.2.9)			
Hydrocyanic acid (HCN)	N[b]	N[b]	ARfD: 20 for cyanide (EFSA, 2019b)
Cleaning agents and disinfectants (section 3.2.14)			
Perchlorate	N[b]	TDI 0.3 (EFSA, 2014c)	N[b]
Surfactants (NP, AS, LAS)	N[b]	N[b]	N[b]
Other chemical hazards (section 3.2.13)			
Phthalates (DEHP, DIDP, DiNP)	N[b]	group-TDI for DBP, BBP, DEHP and DINP: 50 (EFSA, 2019c)	N[b]

[a] Legal limits from Regulation (EC) No 1881/2006.

[b] N, no information available.

Table 3 *Toxicological information for the prioritised pesticides based on the EU pesticides database.*

Pesticides	EU MRLs (mg/kg) for most relevant bulbs tubers, stem and root vegetables[a]	ADI (mg/kg bw/day)	ARfD (mg/kg bw)	EU approval
Azoxystrobin	Leek: 10, carrot: 1	0.2	NA[b]	Yes
Boscalid	Leek: 9, carrot: 2	0.04	NA[b]	yes
Chlorpyrifos	Leek: 0.01, carrot: 0.1	0.001	0.005	No
Difenoconazole	Leek: 0.6, carrot: 0.4	0.01	0.16	Yes
Dithiocarbamates[c]:	Leek: 3			
Maneb		0.05	0.2	No
Mancozeb		0.05	0.6	Yes
Metiram		0.03	NA[b]	Yes
Propineb		0.007	0.1	No
Thiram		0.01	0.025	No
ziram		0.006	0.08	yes
Fenbutatin oxide	Leek: 0.01	0.05	0.1	No
HCH	Bamboo shoots: 0.01	NE[d]	NE[d]	No
Iprodione	Leek: 0.01	0.02	0.06	No
Methiocarb	Leek: 0.2	0.00025	0.0005	No
Linuron	Carrot: 0.01	0.003	0.03	No
PCNB (Quintozene)	Bamboo shoots: 0.02	0.01	NA[b]	No
Pendimethalin	Leek:0.05	0.125	0.3	Yes
Pyraclostrobin	Leek: 0.8	0.03	0.03	Yes
Tebuconazole	Leek: 0.6	0.03	0.03	Yes
Zoxamide	Leek	0.5	NA[b]	Yes

a Most relevant underground vegetables are those vegetables in which the pesticides were frequently found and/or in which MRL exceedances were found (see Table 1).

b NA, not applicable.

c dithiocarbamates comprises a group of substances including maneb, mancozeb, metiram, propineb, thiram and ziram.

d NE, not established.

3.5.1 Aluminium (Al)

Food is the major route of exposure to Al for the general population. Al may persist for a long time in the human body before it is excreted via the urine. Al has been shown to be neurotoxic and nephrotoxic. Neurotoxicity and nephrotoxicity studies were used to derive a NOAEL, which was used to set a TWI of 1 mg/kg bw/week. The estimated daily dietary exposure in Europe is 0.2-2.3 mg/kg bw/day, so the TWI is likely to be exceeded in a significant part of the population. Monitoring data gathered by EFSA showed that most unprocessed foods contained less than 5 mg/kg of Al, while higher mean concentrations of 5-10 mg/kg were often found in among others vegetables. For the underground vegetables, radish was specifically indicated as a vegetable that can contain 5-10 mg/kg. Vegetables were considered as one of the major contributors to the dietary Al exposure (>10%), but no detailed conclusion on for example the contribution of specific bulb, root, stem and tuber vegetables could be made, because of a lack of detailed information in the used total diet studies (EFSA, 2008d).

3.5.2 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 previously 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. Bulb, root, stem and tuber vegetables were not mentioned as main contributor to dietary inorganic exposure (EFSA, 2014a).

RIVM performed an assessment on the human health risk of growing vegetables for private use in soil contaminated with arsenic. Exposure to arsenic from vegetable that people grow themselves was shown to contribute to about only 10% of the exposure from purchased food products such as, rice, cereals, milk and drinking water (Swartjes et al., 2017).

3.5.3 Cadmium (Cd)

EFSA concluded that the main source of Cd exposure for the non-smoking general population is food. Cd is toxic to the kidney, especially to the proximal tubular cells, where Cd accumulates (half-life: 10-30 years) and may cause renal dysfunction. This can progress after prolonged or high exposure to renal failure. Cd is also classified as human carcinogen Group 1 IARC. The TWI of Cd was set at 2.5 μg/kg bw/week, which corresponds to a TDI of 0.357 μg/kg bw/day (EFSA, 2009b).

Based on detailed individual food consumption data, EFSA made a better estimation of the dietary intake of Cd in 2012 (EFSA, 2012a). Foods that are consumed in larger quantities have the greatest impact on the dietary Cd exposure. This was the case for the broad food categories of grains and grain products (26.9%), vegetable and vegetable products (16%) and starch roots and tubers (13.2%). In the vegetables category, root vegetables were important for the contribution to the exposure of Cd in younger children. Carrot was the most common root vegetable covering 80% of the exposure from this root vegetable category (2.2% of the total contribution). Potatoes and potato products were mainly responsible for the exposure from the starch roots and tubers category.

An average weekly dietary exposure of Cd was estimated at 2.04 μg/kg bw per week and a high exposure (P95) was estimated at 3.66 μg/kg bw per week. This review confirmed that the 95^{th} percentile exposure could exceed the TWI. There is a small margin between the dietary exposure and the TWI. Although the risk for adverse effects on kidney function is low, EFSA concluded that the current exposure to Cd should be reduced at population level (EFSA, 2012a).

RIVM concluded in 2015 that the median daily intake in the Netherlands exceeded the TDI (0.357 μg/kg bw/day) up to the age of about 10. However, the life-long Cd exposure estimates were lower (0.25 μg/kg bw/day) than the TDI, because of a much lower intake at later ages. Therefore, the risk of developing kidney failure due to life-long exposure was regarded as negligible for the general population. Cereals and potatoes were important contributors to the exposure of Cd due to the high consumption of these food products. Vegetables and fruits were also important contributors, in which spinach and pineapple had the highest contribution. The refined model used in this RIVM study showed that the long-term intake was lower than calculated by EFSA in 2012 (Spong and Boon, 2015).

3.5.4 Lead (Pb)

The major exposure route to Pb is via food. Pb can accumulate in the skeleton of the human body; the half-life in bones is 10-30 years. In blood, the half-life of Pb is approximately 30 days. The main target organ of Pb toxicity is the central nervous system. Neurotoxicity associated with Pb can affect the short-term verbal memory, fine motor skills, information processing and can cause psychiatric symptoms. In 2010, EFSA established a new HBGV as the previously established PTWI was concluded to be no longer appropriate. 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 estimated mean exposure for young children was higher than the $BMDL_{01}$ of 0.5 μg/kg bw/day. For adults, the respective BMDLs for cardiovascular effects ($BMDL_{01}$ of 1.5 μg/kg bw/day) and nephrotoxicity ($BMDL_{10}$ of 0.63 μg/ kg bw/day) were not exceeded by the estimated mean exposure for adults (EFSA, 2012b).The broad food categories contributing the most to Pb 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%). The main contributors in the vegetables and vegetable product category were leafy vegetables (2.0%), fruiting vegetables (1.8%), and root vegetables

(0.9%) in particular carrots. In the category of vegetables, root and fruiting vegetables were more important in very young children while leafy vegetables were more important with increasing age.

RIVM concluded that because of the dietary intake of Pb in the Netherlands detrimental health effects cannot be excluded for children up to 7 years of age, pregnant women and adults. The food groups contributing the most to the dietary intake of Pb were the same as the groups mentioned by EFSA. Grains and grain-based products, non-alcoholic beverages, vegetables and vegetable products and milk and dairy products, were the main food groups contributing to the exposure of lead (in total 61%) for persons aged 7-69. In children (2-6 years), the main contributors were grains and grain-based products, fruits and fruit products, milk and dairy products, sugar and confectionary and vegetables and vegetables products (total 74%). Next to these groups, starchy roots and tubers also contributed at least 5% of the total contribution for all age categories. Data of Pb concentrations in food products from other countries were also used because of limited Dutch data for some food products (Boon et al., 2017).

3.5.5 Polycyclic aromatic hydrocarbons (PAHs)

PAHs can be considered mutagenic, genotoxic, and carcinogenic to humans (EFSA, 2008b; International Agency for Research on Cancer (IARC), 2018). For non-smokers, the major route of exposure is via food. EFSA used the margin of exposure (MOE) approach considering $BMDL_{10}$ values to evaluate potential concerns for human health. For the carcinogenic PAHs in food, a $BMDL_{10}$ of 0.49 mg/kg bw/day was selected for PAH8 as a marker. For high end consumers (P97.5) only, the margin of exposure (MOE) was around 10,000, which indicates a potential concern for human health (EFSA, 2008c).

Cereals and cereal products together with seafood and seafood products have the highest contribution to consumer PAH exposure (median value of 67 and 36 ng BaP/day, respectively). Vegetables or bulb, root, stem and tuber vegetables were not indicated as contributors to the dietary PAH intake (EFSA, 2008c).

3.5.6 Nitrate

Vegetables are the main contributors to human exogenous exposure to nitrate; to a lesser extent, exposure also occurs via other food products and water. Nitrate is also endogenously formed. Nitrate is relatively non-toxic. However, metabolites and reaction products, such as nitrite, nitric oxide and N-nitroso compounds have been shown to give adverse health effects. The adverse effects are among others methaemoglobinaemia and some evidence for carcinogenic effects. An ADI of 3.7 mg/kg bw/day has been derived by EFSA and was also confirmed by JECFA. EFSA estimated that the ADI was not exceeded in a conservative case assuming a consumption of 400 grams mixed vegetables per day. For a small part of the population, which consumes a high amount of leafy vegetables, such as rucola, the ADI for nitrate could be exceeded. Overall, EFSA concluded that the estimated exposures are unlikely to pose a risk for human health (EFSA, 2008a).

The type of vegetables consumed and the corresponding nitrate levels have a high impact on the dietary exposure, more than the total amount of vegetables consumed (median nitrate concentration was 255 mg/kg). The highest nitrate values were found for leafy vegetables. Median nitrate concentration for total roots and tubers was 152 mg/kg and for bulb vegetables the median concentration was 60 mg/kg. These values are relatively low. However, carrot for example could be a major component in the diet (EFSA, 2008a).

3.5.7 Aflatoxins

Aflatoxins are genotoxic and carcinogenic. Aflatoxin B_1 is the most potent genotoxic and carcinogenic aflatoxin and the most common aflatoxin in food. Exposure to aflatoxins through food should be kept as low as possible. Aflatoxins have primarily been detected in imported foods, like peanuts, tree nuts, dried fruit, spices and crude oil, cocoa beans, maize and rice. EFSA opinions specifically focused on nuts, because these contribute the most to the total dietary exposure of aflatoxins (EFSA, 2007, 2018c). No specific information was thus found on the contribution of underground vegetables to the aflatoxin dietary exposure.

3.5.8 Fumonisins

EFSA established a TDI for fumonisin B_1 of 1 µg/kg bw per day. This was based on increased incidence of magalocytic hepatocytes in mice after chronic exposure. Based on toxicity, mode of action and structural similarities of fumonisin $B_{2\text{-}4}$, they were included in a group TDI with B_1. Several modified forms of fumonisins can be found; these are phase I and phase II metabolites formed in fungi, plants or animals However, these could not be included in the group TDI, because of a lack of data. In general, fumonisins are mainly produced by *Fusarium verticillioides* and *F. proliferatum*, and predominately found in maize and sorghum. FB_2 and FB_4, produced by *Aspergillus sec. Nigri* can be found in vegetables (EFSA, 2018b). No exposure assessment has been performed by EFSA for fumonisins in food.

3.5.9 Moniliformin

Limited toxicological information is available about the mycotoxin moniliformin. Therefore, chronic or acute HBGVs could not be established by EFSA. MOEs between a NOAEL (6 mg/kg bw) and a $BMDL_{05}$ (0.2 mg/kg bw/day) were calculated for acute and chronic exposure. These MOEs indicated a low risk for human health. However, there was a high uncertainty. For all age groups, the highest contributors to the dietary exposure of moniliformin were grain-based products. Fruits and fruit products were also relevant contributors for infants and young children, and composite foods for adults (EFSA, 2018f).

3.5.10 Hydrocyanic acid (HCN)

Recently, EFSA assessed the human health risks related to the presence of hydrocyanic acid (HCN) in foods other than raw apricot kernels. In the EFSA opinion, the term cyanide was used, because HCN normally exists as a mixture of non-dissociated acid (HCN) and dissociated cyanide ions in aqueous biological fluids. It was concluded that the ARfD for cyanide of 20 µg/kg bw as established in 2016 for raw apricot kernels was applicable for acute effects of cyanide independent of the food product. Based on a human bioavailability study, factors to correct for differences in the bioavailability for different food products were derived. For cassava and cassava derived products, this factor is 1 meaning that concentrations found are bioavailable and no correction is needed for the exposure assessment.

It was not possible to derive a chronic HBGV due to limited available data. Chronic and acute dietary exposure to cyanide from food products were estimated. However, no occurrence data were available for cassava. Main contributors to acute and chronic exposure of cyanide from the diet for all age groups were biscuits, juice or nectar and pastries and cakes. Mean dietary exposure did not exceed the ARfD for all age groups. At P95, intake the ARfD was exceeded for some age groups. However, EFSA concluded that it was unlikely that this would result in adverse effects, taken into account the conservatism in the exposure assessment. Data on chronic toxicity was not sufficient to determine possible human health risks (EFSA, 2019b).

3.5.11 Perchlorate

EFSA established a TDI of 0.3 µg/kg bw/day for perchlorate. They concluded that dietary intakes are far too low to cause acute toxicity. Therefore, an ARfD was not warranted. The chronic exposure to perchlorate is of potential concern. High exposure to perchlorate can lead to inhibition of thyroid iodine uptake, which could lead to multinodular toxic goitre, in particular in the population with iodine deficiency (EFSA, 2014c). Important contributors to the dietary exposure of perchlorate were vegetable and vegetable products, dairy products and fruit and fruit products. Relatively high mean occurrence values were found for among others radishes (117 µg/kg) (EFSA, 2017b).

3.5.12 Phthalates

EFSA has derived a group-TDI of 50 µg/kg bw/day for the phthalates di-butylphthalate (DBP), butylbenzyl-phthalate (BBP), bis(2-ethylhexyl)phthalate (DEHP) and di-isononylphthalate (DINP) relative to DEHP as a reference substance. The estimated dietary exposure of DBP, BBP, DEHP and DINP contributed for 1.8-14% of the group-TDI. For high (P95) consumers, the dietary exposure contributed to 3-23% of the group-TDI. Vegetables were not mentioned as main contributors to the dietary exposure of the phthalates as assessed in the EFSA opinion, only vegetable oil was mentioned as a one of the main contributors to the dietary exposure (EFSA, 2019c). A Belgian study assessed the dietary intake of 8 phthalates, which showed that the intake of DEHP was highest followed by iisobutyl phthalate (DiBP). BBP, di-n-butyl phthalate (DnBP) and diethyl phthalate (DEP) were far below the TDI. However, the 99th percentile intake of young children (2.5 to 6.5 years old) reached 80% of the TDI for DEHP. The main contributor in this case was bread (Sioen et al., 2012).

3.6 Trends in bulbs, tubers and root vegetables

Previously, trends were evaluated for the vegetable chain in general. Results of this analysis are described in the report on leafy vegetables (Banach et al., 2019). In short, consumer trends were identified such as increased demand for convenience products and increased attention for human health aspects resulting in an expected increase in vegetable consumption. This is also noticed for underground vegetables; for instance, the vegetables parsnip and yacon are becoming more popular in the EU nowadays (Biojournaal, 2016; Rabobank, 2017; Rompaey, 2017). The previous trend analysis described that carbohydrate-rich food products are increasingly replaced by alternative products made of vegetables. An example thereof for underground vegetables is a taco made of yam (Culy.nl, 2019). Examples on the Dutch market are depicted in Figures 2-5.

Figure 2 *Pancake mix with beet roots.*

Figure 3 *Pizza with beet roots.*

Figure 4 *Crisps from beet roots and carrots.*

Figure 5 *Wraps from carrots.*

Furthermore, consumer behaviour is changing as a result of increased importance of sustainability and circularity. As a result, food waste is being diminished, for example, by reusing rest materials as ingredients for ready-to-prepare packages, such as soups. Another development related to sustainability is the increased use of biodegradable packaging. The analysis also showed that there is an increased interest in the use of effluent and sludge products in open field cultivation due to the movement towards a more circular economy. With respect to production and trade of vegetables, a relevant trend is the increased production of organic vegetables. Furthermore, production is influenced by climate change. The expected increased temperatures may lead to the introduction of other chemical hazards or the increase of known food safety hazards. The evaluation of trends also showed that vegetable trade is a global market allowing for product diversity in retail. As a result, the supply chain is complex. However, labelling is improving and the increase in intelligent packaging allows for an increased transparency of the vegetable supply chain. Analysis of legal and policy aspects showed that pesticide regulation is becoming stricter, which is expected to decrease pesticide residues in vegetable products.

Overall, an important trend with respect to food safety is the interest in the use of treated wastewater and sludge in open field cultivation. This may lead to the presence of e.g. pharmaceuticals in vegetables. Mendez et al. (2016), for example, showed that although triclosan levels degrade over time in the soil, the presence of triclosan will retain in the soil when it is continuously irrigated with contaminated water. Outside the Netherlands, treated wastewater is currently used for irrigation purposes. Furthermore, due to the increased interest in a circular economy, these practices may be a future scenario for the Netherlands as well. Another important trend is the expected increased temperatures in summer, which may lead to increased levels of cyanotoxins in irrigation water that eventually may end up in vegetables produced in open field.

3.6.1 Product introductions

Additional to the general trends summarised above, trends specific for underground vegetables were evaluated consulting the Innova database by WFBR: "The Innova database showed that ginger and horseradish are in a different category than the other vegetables as these are more used in spice applications. A five-fold increase was seen in the number of product introductions for these two vegetables in the period 2009-2018. The other vegetables evaluated in the Innova database (i.e. asparagus, beetroot, carrots, celeriac, garlic, kohlrabi, leek, nopal, onion, parsnip, radish, salsify, shallot, swede, sweet potato, tigernut, turnip, water chestnut and yacon) also show a clear increase in product introductions over the past years (see Figure 6). The main market categories in which the introductions were shown are 'Sauces & Seasonings' and 'Ready Meals & Side Dishes'.

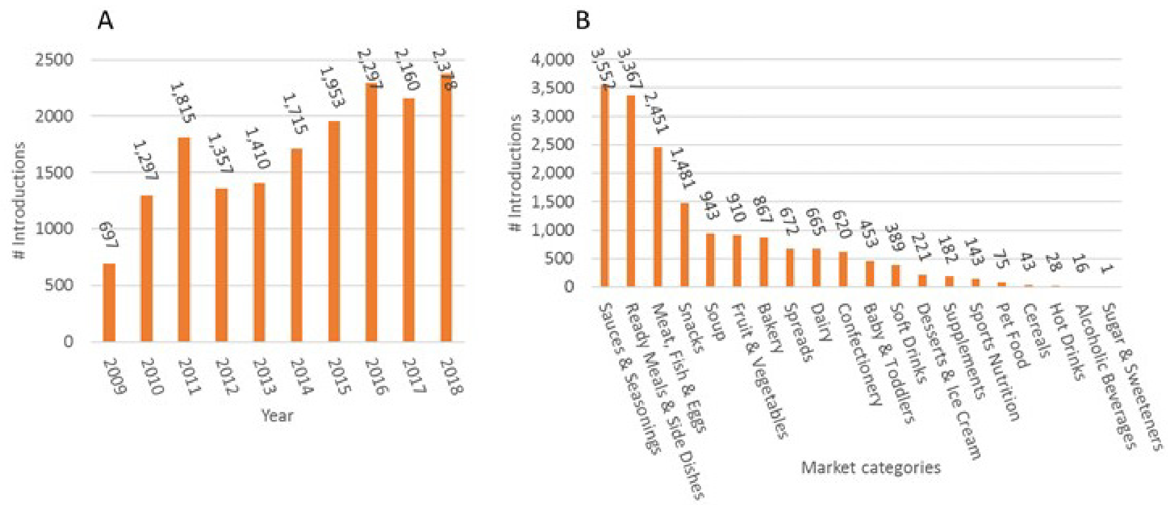

Figure 6 *A) Annual introductions of product innovations based on underground vegetables in the Netherlands, B) Market categories of the introductions.*

The introduction in the 'Sauces & Seasonings', 'Meat, Fish & Eggs' and 'Snacks' categories primarily used onion or garlic as spice. In the categories 'Ready Meals & Side Dishes' and 'Soup' most product introductions were processed, although a few 'Do It Yourself' meals and dishes appeared in these categories as well. Most of the 'Do It Yourself' dishes, however, were found in the 'Fruit & Vegetables' category, that showed fluctuating number of introductions in the past ten years" (Hayrapetyan et al., 2019).

4 Conclusions

This report describes the results of a literature study on the chemical hazards that can be found in underground vegetables (i.e. bulb, root, tuber and stem vegetables) produced and/or consumed in the Netherlands. Based on the literature review and advanced search using Google, a long list of chemical hazards was established that can be found in underground vegetables.

The long list of chemical hazards for underground vegetables consisted of:
- Environmental contaminants, i.e. heavy metals and other elements, PFAS, PAHs, nitrate, pharmaceutical compounds and radionuclides;
- Residues of plant protection products used during cultivation;
- Natural contaminants, i.e. mycotoxins and plant toxins;
- Processing contaminants;
- Residues of cleaning agents and disinfectants used in the supply chain;
- Other chemical hazards such as nanoparticles, microcystins and phthalates.

Those hazards that were frequently found in underground vegetables, detected at concentrations above legal limits, and/or detected at concentrations that would lead to an exceedance of HBGV or for which underground vegetables were indicated to be the main dietary intake source were included on the so-called intermediate list.

The intermediate list contained:
- The heavy metals As, Cd and Pb
- PAH8
- Nitrate
- 15 Plant protection products. However, since this list is only based on literature review, it is recommended to complement this list with the results of the Dutch monitoring program.
- The mycotoxins aflatoxin B1 and fumonisins
- The plant toxin HCN
- Perchlorate
- Phthalates

For some chemical hazards, information obtained was too limited to indicate whether they should be included on the intermediate list. These chemical hazards were identified as knowledge gaps:
- The element Al
- The pharmaceuticals lamotrigine and 10,11 epoxycarbamazepine
- The mycotoxin moniliformin
- Surfactants (NP, AS, LAS)

Toxicological information (such as the contribution of underground vegetables to the dietary intake and HBGVs) were collected for the chemical hazards on the intermediate list and the hazards identified as knowledge gaps. This information can be used to derive a short list of chemical hazards that are most relevant for underground vegetables produced and/or consumed in the Netherlands. Chemical hazards on the short list are advised to be included in the monitoring program due to their potential risk to human health.

As indicated previously for leafy vegetables (Banach et al., 2019), a relevant trend identified is the use of treated wastewater and sludge in open field cultivation, which may lead to the presence of pharmaceutical compounds in vegetables. Another important trend for food safety is climate change, which may result in cyanotoxins that may be taken up in vegetables via irrigation water. Furthermore, vegetables such as beetroot are increasingly used as replacement of carbohydrate-rich food, which may result into an increased intake of chemical hazards from consumption of underground vegetables.

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Annex 1 List of abbreviations

Abbreviation	English	Dutch
238U	Uranium-238	Uranium-238
90Sr	Strontium-90	Strontium-90
ACE	Acenaphthene	Acenafteen
ACY	Acenaphthylene	Acenaftyleen
ADI	Acceptable daily intake, a HBGV for the chronic effects of compounds in food and drinking water	Aanvaardbare dagelijkse inname
Ag	Silver	Zilver
aHI	Acute hazard index (= EDI/ ARfD * 100%)	Gevaarindicator voor acute blootstelling
Al	Aluminium	Aluminium
ANT	Anthracene	Antraceen
ARfD	Acute reference dose, a HBGV for the acute effects of compounds in food and drinking water	Acute referentie dosis
AS	Alkylsulfates	Alkylsulfaten
As	Arsenic	Arseen
BaA	Benz(a)anthracene	Benz(a)antraceen
BAC	Benzalkonium chloride	Benzalkoniumchloride
BaP	Benzo(a)pyrene	Benzo(a)pyreen
BbF	Benzo(b)fluoranthene	Benzo(b)fluoranteen
BfR	Bundesinstitut für Risikobewertung (German Federal Institute for Risk Assessment)	Duits federale instituut voor risicobeoordeling
BkF	Benzo(k)fluoranthene	Benzo(k)fluoranteen
$BMDL_{01}$/$BMDL_{10}$	Benchmark Dose Lower confidence limit (lower limit of the 95% confidence interval of the dose that results in a low (1 or 10%) health response)	De ondergrens van het 95%-betrouwbaarheidsinterval van de ‘Benchmark’ dosis
BPE	Benzo(ghi)perylene	Benzo(ghi)peryleen
BuRO	Office for Risk Assessment and Research	Bureau Risicobeoordeling & onderzoek
bw	Body weight	Lichaamsgewicht
CBZ	Carbamazepine	Carbamazepine
Cd	Cadmium	Cadmium
CdCl2	Cadmium chloride	Cadmiumchloride
CECs	Contaminants of emerging concern	Opkomende gevaren
CHR	Chrysene	Chryseen
CIP	Ciprofloxacin	Ciprofloxacin
CLA	Clarithromycin	Clarithromycin
Co	Cobalt	Kobalt
Cr	Chromium	Chroom
Cu	Copper	Koper
CYN	Cylindrospermopsin	Cylindrospermopsin
DBA	Dibenzo(a,h)anthracene	Dibenzo(a,h)antraceen
DCF	Diclofenac	Diclofenac
DDAC	Didecyldimethylammonium chloride	Didecyldimethylammoniumchloride
DDT	1,1,1-trichlor-2,2-bis-(p-chlorophenyl) ethane	1,1,1-trichloor-2,2-bis- (p-chloorfenyl) ethaan
DEHP	Bis(2-ethylhexyl)phthalate	Bis(2-ethylhexyl)ftalaat
DiDP	Diisodecyl phthalate	Diisodecylftalaat
DiNP	Diisononyl phthalate	Diisononylftalaat
DON	Deoxynivalenol	Deoxynivalenol
DW	Dry weight	Drooggewicht
EDI	Estimated daily intake	Geschatte dagelijkse inname
EFSA	European Food Safety Authority	Europese Voedselautoriteit
ENR	Enrofloxacin	Enrofloxacin
EU	European Union	Europese Unie

Abbreviation	English	Dutch
Eurostat	European Statistical Office	Europees Bureau voor de Statistiek
FAO	Food and Agricultural Organization of the United Nations	Voedsel- en Landbouworganisatie van de Verenigde Naties
FAVV	Federal Agency for the Safety of the Food Chain (Belgium)	Federaal Agentschap voor de veiligheid van de voedselketen (België)
Fe	Iron	IJzer
FLA	Fluoranthene	Fluoranteen
FLU	Fluorene	Fuoreen
FSANZ	Food Standards Australia New Zealand	Voedselveiligheidsautoriteit van Australië en Nieuw-Zeeland
FW	Fresh weight	Versgewicht
GAP	Good Agricultural Practices	Goede landbouwpraktijken
HBGVs	Health based guidance values	Gezondheidskundige richtwaarden
HCH	Hexachlorocyclohexane	Hexachloorcyclohexaan
HCN	Hydrocyanic acid	Waterstofcyanide
Hg	Mercury	Kwik
HQ	Hazard quotient (= EDI/ADI * 100%)	Risicoquotiënt
IP	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyreen
JECFA	Joint FAO/WHO Expert Committee on Food additives	Comité van deskundigen voor Levensmiddelenadditieven van de FAO/WHO
LAS	Linear alkylbenzene sulfonates	Lineaire alkylbenzeen sulfonaten
LB	Lower bound (levels < LOD are replaced with zeros)	Ondergrens
LOD	Limit of detection	Detectielimiet
LOQ	Limit of quantification	Bepaalbaarheidsgrens
MC	Microcystin	Microcystine
MOE	Margin of Exposure (Ratio between a point on the dose response curve (e.g. NOAEL or BMD) and the exposure)	Blootstellingsmarge
ML	Maximum level; the maximum concentrations of contaminants allowed in the edible part of a food product ((EU) 1881/2006)	Maximumgehalte
Mn	Manganese	Mangaan
MRL	Maximum residue limit; the highest level of a pesticide/VMP residue that is legally tolerated in or on food or feed when applied correctly ((EU) 37/2010 and (EC) 396/2005)	Maximumwaarde voor residuen
NAP	Naphthalene	Naftaleen
Ni	Nickel	Nikkel
NOAEL	No observed adverse effect level	Dosis waarbij geen negatieve effecten zijn geobserveerd
NOR	Norfloxacin	Norfloxacin
NPs	Nanoparticles	Nanodeeltjes
NPX	Naproxen	Naproxen
NVWA	Netherlands Food and Consumer Product Safety Authority	Nederlandse Voedsel- en Warenautoriteit
PAH8	Sum of 8 PAHs: BaP, BaA, BbF, BkF, BPE, CHR, DBA and IP	Som van 8 PAK's: BaP, BaA, BbF, BkF, BPE, CHR, DBA en IP
PAHs	Polycyclic Aromatic Hydrocarbons	Polycyclische aromatische koolwaterstoffen (PAK's)
Pb	Lead	Lood
PCBs	Polychlorinated biphenyls	Polychloorbifenylen
PCNB	Pentachloronitrobenzene	Pentachloornitrobenzeen
PFASs	Per- and polyfluoroalkyl substances	Per- en polyfluoralkylverbindingen
PFBuA	Perfluorobutanoic acid	Perfluorbutaanzuur
PFHpA	Perfluoroheptanoic acid	Perfluorheptaanzuur
PFHxA	Perfluorohexanoic acid	Perfluorhexaanzuur
PFOA	Perfluorooctanoic acid	Perfluoroctaanzuur
PFOS	Perfluorooctanesul-fonic acid	Perfluoroctaansulfonaat
PFPeA	Perfluoropentanoic acid	Perfluorpentaanzuur
PHE	Phenanthrene	Fenantreen

Abbreviation	English	Dutch
PMTDI	Provisional maximum tolerable daily intake	Voorlopige maximaal toelaatbare dagelijkse inname
POPs	Persistent organic pollutants	Persistente organische verontreinigende stoffen
PPCPs	Pharmaceutical and personal care products	Farmaceutische producten en producten voor persoonlijke verzorging
PPP	Plant protection product	Gewasbeschermingsmiddel
PTW	Primary treated wastewater	Primair behandeld afvalwater
PYR	Pyrene	Pyreen
RfD	Reference dose, a HBGV for the chronic effects of compounds in food and drinking water as established by the US EPA	Referentiedosis
SDZ	Sulfadiazine	Sulfadiazine
STW	Secondary treated wastewater	Secundair behandeld afvalwater
TCS	Triclosan	Triclosan
TDI	Tolerable daily intake	Toelaatbare dagelijkse inname
TiO_2-NPs	Titanium dioxide	Titaniumdioxide
TTC	Threshold of toxicological concern	Toxicologische gevarendrempel
TTW	Tertiary treated wastewater	Tertiair behandeld afvalwater
TWI	Tolerable weekly intake	Toelaatbare wekelijkse inname
UB	Upper bound (Levels < LOD are placed with the LOD)	Bovengrens
UL	Tolerable Upper Intake Level; the maximum level of total chronic intake of a nutrient to be unlikely to pose a risk of adverse human health effects (EFSA)	Maximumwaarde
US	United States	Verenigde Staten
VMP	Veterinary Medicinal Product	Diergeneesmiddel
WFBR	Wageningen Food & Biobased Research	
WFSR	Wageningen Food Safety Research	
WHO	World Health Organization	Wereld Gezondheidsorganisatie
Zn	Zinc	Zink

Annex 2 English-Dutch crop names

English	Dutch
Underground vegetables (meaning: bulb, root, stem, tuber vegetables)	Ondergrondse groenten (daarmee zeggende: bol-, knol-, stam-, wortelgroenten)
Arrowroot	Pijlwortel
Asparagus	Asperge
Ahipa	Ahipa
Arracacha	Arracacha
Bamboo shoot	Bamboescheut
Beetroot	Rode biet
Bulb vegetables	Bolgewassen
Burdock	Klis
Cardoon	Kardoen
Carrot	Wortel
Cassava	Cassave
Celeriac	Knolselderij
Chufa	Knolcyperus
Daikon	Daikon
Florence fennel	Florence venkel
Garlic	Knoflook
Ginger	Gember
Gobo	Klis
Horseradish	Mierikswortel
Jerusalem artichoke	Aardpeer
Jicama	Yamboon
Kohlrabi	Koolrabi
Kurrat	Egyptische prei
Leek	Prei
Lotus root	Lotuswortel
Mooli	Daikon
Nopal	Nopal
Onion	Ui
Parsnip	Pastinaak
Pie plant	Rabarber
Radish	Radijs
Rhubarb	Rabarber
Root parsley	Wortelpeterselie
Root vegetables	Wortelgewassen
Rutabaga	Koolraap
Salsify	Paarse morgenster, boksbaard, haverwortel, witte schorseneren
Samphire	Zeekraal
Scorzonera	Schorseneer
Shallot	Sjalot
Skirret	Suikerwortel
Spring onion	Lente-ui
Stem vegetables	Stengelgroenten
Swede	Koolraap
Sweet potato	Zoete aardappel
Tannia	Tannia
Taro	Taro
Tigernut tuber	Knolcyperus
Tuber vegetables	Knolgewassen
Turnip	Knolraap
Ulluco	Ullucus
Wasabi	Wasabi
Water chestnut	Waterkastanje
Yacon	Appelwortel
Yam	Yam

Annex 3 Subgroups vegetables

In most cases, data was given for a specific vegetable, especially in peer reviewed articles. Nevertheless, this was not always the case for monitoring data as published by several authorities. The authorities BfR, EFSA and FAVV apply the same categorisation to the monitoring data and subgroup vegetables according to Regulation (EC) No 396/2005. Subgrouping of the product group underground vegetables is shown in the following table.

Subgroups	Vegetables
Bulb vegetables	Garlic (*Alium sativum*)
	Onion (*Allium cepa*)
	Shalot (*Allium cepa*, group Aggregatum; syn.: *Allium ascalonicum*)
	Spring onion (*Allium cepa, Allium fistulosum*)
	Other
Stem vegetables	Artichoke (*Cyanara cardunculus*, NB included in Banach et al. (2019)
	Asparagus (*Asparagus officinalis*)
	Bamboo shoot (*Bambusa vulgaris, Phyllostachys edulis*)
	Celery (*Apium graveolens* var. *dulce*, NB included in Banach et al. (2019)
	Cardoon (*Cynara cardunculus*)
	Palm heart (*Bactris gasipaes, Cocos nucifera, Daemonorops jenkinsiana, Euterpe oleracea*)
	Leek (*Allium ampeloprasum*, syn.: *Allium porrum*)
	Rhubarb (*Rhuem rhabarbarum*)
	Fennel (*Foeniculum vulgare* var. *azoricum*)
	Other
Root and tuber vegetables	Potato (*Solanum tuberosum* subsp. *tubersum*, NB included in Nijkamp et al. (2017)
	Jerusalem artichoke (*Helianthus tuberous*)
	Arrowroot (*Maranta arundinacea*)
	Beetroot (*Beta vulgaris* var. *vulgaris*)
	Cassava root/manioc (*Manihot esculenta*)
	Celeriac/turnip rooted celery (*Apium graveolens* var. *rapaceum*)
	Swede/rutabaga (*Brassica napus* subsp. *napobrassica*)
	Parsnip (*Pastinaca sativa*)
	Root parsley (*Petroselinum crispum* convar. *radicosum*, NB included in Banach et al. (2019)
	Radish (*Raphanus sativus*)
	Horseradish (*Armoracia rusticana*)
	Turnip (*Brassica rapa* subsp. *rapa*)
	Salsify (*Tragopogon porrifolius*)
	Carrot (*Daucus carota* subsp. *sativus*)
	Yam (*Dioscorea spp.*)
	Sweet potato (*Ipomoea batatas*)
	Other

Whereas the classification of underground vegetables according to EU legislation is applied in the reports from BfR, EFSA and FAVV, the FAO uses the classification of Codex Alimentarius. The underground vegetables, on which data was given in this report, and their codes according to Codex Alimentarius are given in the table below.

Product code	Vegetables
VA 0035	Bulb vegetables
VA 0381	Garlic
VA 0384	Leek
VS 0621	Asparagus
VR 0075	Root and tuber vegetables
VR 0585	Jerusalem artichoke
VR 0574	Beetroot
VR 0591	Daikon
VR 0578	Celeriac
VR 0497	Swede
VR 0583	Horseradish
VR 0588	Parsnip
VR 0494	Radish
VR0498	Salsify
VR 0505	Taro
VR 0504	Tannia
VR 0577	Carrot
VR 0600	Yam
VR 0508	Sweet potato
VL 0506	Turnip
VB 0405	Kohlrabi

Annex 4 Search terms bulb, root, stem and tuber vegetables

The sort of tuber vegetables, potato, was subject in a separate report previously. Therefore, potato is excluded from this research. Nevertheless, vegetables known as sweet potato are still in scope of this research, due to the exclusion thereof in the previous report on potato.

Two choose relevant vegetable species in this category, two sources (EFSA categorisation; NVWA list ‘Ketenklassen GF’) were consulted.

The EFSA list provided the following information which were taken as a starting point:

- Root and tuber vegetables: including carrots, ahipa, arracacha, bamboo shoot, beetroot, burdock, cassava, Chinese artichoke, chufa, daikon, elephant foot yam, ginger, gobo, Hamburg parsley, horseradish, Jerusalem artichoke, jicama, komatsuna, laos, manioc, mooli, parsnip, radish, rutabaga, salsify, scorzonera, skirret, swede, sweet potato, taro, tigernut, turnip, ulluco, water chestnut, wasabi, yacón, yam
- Bulb and stem vegetables: including asparagus, cardoon, celeriac, celery, elephant garlic, Florence fennel, garlic, kohlrabi, kurrat, leek, lotus root, nopal, onion, Prussian asparagus, shallot, spring onion, welsh onion

This list was compared with the list from the file ‘Ketenklassen GF’. This has led to the addition of the two vegetables, which were not mentioned in the EFSA file:

- Rhubarb (pie plant)
- (marsh) samphire

Additionally, the following names were removed:

- Komatsuna (leafy vegetable)
- Laos (to be included in spices and herbs)
- Celery (covered by leafy vegetable)

The following search strings were used:

1: underground vegetables
asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR “beet root*” OR gobo OR burdock* OR cassava* OR manioc* OR chufa* OR “tigernut tuber*” OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR “parsley root*” OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR “bulb vegetable*” OR “stem vegetable*” OR “tuber vegetable*” OR “root vegetable*” OR “underground vegetable*”

#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*

#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*"

#4 Exclusion terms:
pathogen* OR streptococcus OR listeria OR virus OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung*

#4_adapted (in line with leafy vegetables)
*pathogen** OR *streptococcus* OR *listeria* OR **virus** OR *bacillus* OR *salmonella* OR *clostridium* OR *staphylococcus* OR *outbreak* OR *"foodborne disease*"* OR *fung** OR *campylobacter* OR *"Escherichia coli"* OR *"E. coli"* OR *model** OR analytic* OR *microbio** OR bacteri* OR virol* Or nutri* OR Sweden

The above-mentioned search stings were used to downsize the total number of hits in Scopus and Web of Science to around 300. The table below shows an overview of how the search strings were used to downsize the number of hits to a manageable number. The changes that are made in the search numbers are bolded.

Search nr.	Scopus	Details	Number of hits
1	#1	Title-Abs-Key	320,477
2	#1 **and #2**	Title-Abs-Key	18,411
3	#1, #2 **and #3**	Title-Abs-Key	2,097
4	Idem	Title-Abs-Key **Limited to 2009-2019**	1,394
5	Idem	**#1 in title** #2 and #3 in Title-abs-key	305
6	Idem	**Including** "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*" **in #1**	309
7	#1, #2, #3 **and #4**	And **NOT #4 in title**: (pathogen* OR streptococcus OR listeria OR virus OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung*)	269
8	Idem **#4_adapted**	Additional search terms added: 1. aligned with the exclusion terms used in 'leafy vegetables' 2. 'Sweden' added to exclusion terms (search term 'swede*' results in 57 papers from Sweden)	177

Option 8 was chosen as the final search. It resulted in 177 hits in Scopus and 144 hits in Web of Science.

SCOPUS
TITLE (asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*") AND TITLE-ABS-KEY ("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 TITLE-ABS-KEY ("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*") AND NOT TITLE (pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR Sweden) AND (LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (

PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009))
= 177 hits

Web of Science
TI=(asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*") AND TS=("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 TS=("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*") NOT TI=(pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* Or nutri* OR Sweden)
AND Years 2009-2019
= 144 hits

Annex 5 Results advanced Google search

Before performing the advanced search in Google, a preliminary search of various websites from research or food safety institutes were explored with the aforementioned three search strings. Below, is a complication of those other websites and a justification for excluding them further from the advanced Google search.

Food and Agriculture Organization
Bulb, tuber, root or stem vegetables and food safety 5080 hits
Id. Selected period: 2009-05/11/2019 245 hits
Id. Only pdf file 253 hits
(Vegetable bulb OR tuber OR root OR stem "food safety" site: http://www.fao.org)

Bulb, tuber, root or stem vegetables and risk assessment -->238 hits
Id. Selected period: 2009-05/11/2019 257 hits
Id. Only pdf file 256 hits
(Vegetable bulb OR tuber OR root OR stem "risk assessment" site: http://www.fao.org)

Bulb, tuber, root or stem vegetables and residue or contaminant -->240 hits
Id. Selected period: 2009-05/11/2019 256 hits
Id. Only pdf file 240 hits
(Vegetable bulb OR tuber OR root OR stem "residue OR contaminant" site: http://www.fao.org)

Selected, due to the fact that many hits give a global perspective on food safety and data from all over the world.

European Food Safety Authority
Bulb, tuber, root or stem vegetables and food safety 303 hits
Id. Selected period: 2009-19/08/2019 49 hits
(Vegetable bulb OR tuber OR root OR stem "food safety" site: http://www.efsa.europa.eu/)

Bulb, tuber, root or stem vegetables and risk assessment 160 hits
(Vegetable bulb OR tuber OR root OR stem "risk assessment" site: http://www.efsa.europa.eu/)

Bulb, tuber, root or stem vegetables and residue or contaminant 40 hits
(Vegetable bulb OR tuber OR root OR stem "residue OR contaminant" site: http://www.efsa.europa.eu/)

Selected, due to the fact that The Netherlands is a Member State of the EU and many goods are imported from other Member States within the EU.

Federal Agency for the Safety of the Food Chain
Bulb, tuber, root or stem vegetables and food safety 46 hits
(Vegetable bulb OR tuber OR root OR stem "food safety" site: www.afsca.be)

Bulb, tuber, root or stem vegetables and risk assessment 41 hits
(Vegetable bulb OR tuber OR root OR stem "risk assessment" site: www.afsca.be)

Bulb, tuber, root or stem vegetables and food safety 29 hits
(Vegetable bulb OR tuber OR root OR stem "residue OR contaminant" site: www.afsca.be)

Selected, due to the fact that many respective vegetables are imported from Germany.

Food Standards Australia New Zealand
Bulb, tuber, root or stem vegetables and food safety 528 hits
Id. Selected period: 2009-19/08/2019 60 hits
(Vegetable food safety bulb OR tuber OR root OR stem site: www.foodstandards.gov.au/)

Not selected, due to the geographical distance to The Netherlands and imported goods are not to barely imported from this area.

Bundesinstitut für Risikobewerting
Bulb, tuber, root or stem vegetables and food safety 16 hits
(Vegetable bulb OR tuber OR root OR stem "food safety " site: https://www.bfr.bund.de)

Bulb, tuber, root or stem vegetables and risk assessment 21 hits
(Vegetable bulb OR tuber OR root OR stem "risk assessment" site: https://www.bfr.bund.de)

Bulb, tuber, root or stem vegetables and residue or contaminant 13 hits
(Vegetable bulb OR tuber OR root OR stem "residue" OR "contaminant" site: https://www.bfr.bund.de)
Selected, due to the fact that many respective vegetables are imported from Germany.

An overview of the number of hits with the three search strings and corresponding search criteria for the four websites is provided in Table A5.1. The total number of hits per website is specified, followed by the total relevant hits and, in parentheses, the total number of hits included in the report.

Table A5.1 *Number of hits in advanced Google search.*

Searches	EFSA[a]	FAVV[b]	BfR[c]	FAO[d]
1. Bulb, tuber, root or stem vegetables AND "food safety"	303	**46**	**16**	5080
Id., 2009-15/04/2019	**49**			245
Id., only PDF				**253**
2. Bulb, tuber, root or stem vegetables AND "risk assessment"	**160**	**41**	**21**	**238**
Id., 2009-15/04/2019				257
Id., only PDF				256
3. Bulb, tuber, root or stem vegetables AND (contaminant OR residue)	**40**	**29**	**13**	**240**
Id., 2009-15/04/2019				256
Id., only PDF				240
total hits	**249**	**116**	**50**	**731**
total relevant hits	**6**	**4**	**3**	**6**

a https://www.efsa.europa.eu/

b https://www.afsca.be/

c https://www.bfr.bund.de

d http://www.fao.org

Numbers in bold are the selected hits for further screening.

Annex 6 Results additional search

The search for additional literature was carried out in Scopus. The following search strings were considered:

#1 Food products
asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR artichoke* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*"
#1 in title

#2 Food contaminant
"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*
#2 in title, abstract and keywords

#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*"
#3 in title, abstract and keywords

#4 Nitrate
nitrate*

#5 POPs
"persistent organic pollutant*" OR POP* OR "perfluoroalkyl compound*" OR "perfluoroalkyl substanc*" OR pfas OR pfoa OR pfos OR polychlorinated biphenyl* OR pcb* OR dioxin*

#6 Processing aids and additives
"processing aid*" OR additive*

#7 Radionuclides
radionuclide*

#8 Pharmaceutical compounds
pharmaceutical* OR "anti-biotic*" OR "anti-microbial*"

#9 Plant toxins
pa* OR "pyrrolyzidine alkaloid*" OR ta* OR "tropane alkaloid*"

#4-9 in title, abstract and keywords

#10 Hazards
nitrate* OR "perfluoroalkyl compound*" OR pfas OR pfoa OR pfos OR polychlorinated biphenyl* OR pcb* OR dioxin* OR "processing aid*" OR additive* OR radionuclide*

#10 in title, abstract and keywords

#11 Exclusion terms
pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR sweden

#11 for AND NOT

Options	Search strings	Details	Hits
1	#1 AND #2 AND #10 AND NOT #11		45
2	#1 AND #10 AND NOT #11	Many hits on the application of plant based materials (not food related	404
3	Id.	Limited from year 2010-present	201
4	#1 AND #3 AND #10 AND NOT #11	Relevant hits, but not all of them (appr. 3 on cassava flour as additive etc.)	9
5	#1 AND #3 AND #4 AND NOT #11		6
6	#1 AND #3 AND #5 AND NOT #11		1
7	#1 AND #3 AND #6 AND NOT #11		2
8	#1 AND #3 AND #7 AND NOT #11		0
9	#1 AND #3 AND #8 AND NOT #11		3
10	#1 AND #3 AND #9 AND NOT #11	Many hits with the word "paper".	187

Selected options:

Option 5;
(TITLE (asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR artichoke* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*")) AND (TITLE-ABS-KEY ("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*")) AND (TITLE-ABS-KEY (nitrate*)) AND NOT (pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR sweden)

Option 6;
(TITLE (asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR artichoke* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*")) AND (TITLE-ABS-KEY ("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*")) AND (TITLE-ABS-KEY ("persistent organic pollutant*" OR pop* OR "perfluoroalkyl compound*" OR "perfluoroalkyl substanc*" OR pfas OR pfoa OR pfos OR polychlorinated AND biphenyl* OR pcb* OR dioxin*)) AND NOT (pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR sweden)

Option 7;
(TITLE (asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR artichoke* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*")) AND (TITLE-ABS-KEY ("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*")) AND (TITLE-ABS-KEY ("processing aid*" OR additive*)) AND NOT (pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR sweden)

Option 8;
(TITLE (asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR artichoke* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*")) AND (TITLE-ABS-KEY ("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*")) AND (TITLE-ABS-KEY (radionuclide*)) AND NOT (pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR sweden)

Option 9;
(TITLE (asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR artichoke* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*")) AND (TITLE-ABS-KEY ("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*")) AND (TITLE-ABS-KEY (pharmaceutical* OR "anti-biotic*" OR "anti-microbial*" OR gentamicin OR triclosan)) AND NOT (pathogen* OR streptococcus OR listeria

OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR sweden)

Option 10;
(TITLE (asparagus OR cardoon* OR celeriac* OR garlic* OR fennel* OR kohlrabi* OR kurrat* OR leek* OR lotus* OR nopal* OR onion* OR shallot* OR carrot* OR ahipa* OR arracacha* OR "bamboo shoot*" OR beetroot* OR "beet root*" OR gobo OR burdock* OR cassava* OR manioc* OR artichoke* OR chufa* OR "tigernut tuber*" OR daikon* OR mooli* OR ginger* OR "root* parsley*" OR "parsley root*" OR horseradish* OR jicama* OR parsnip* OR radish* OR rutabaga* OR swede* OR salsif* OR scorzonera OR skirret* OR "sweet potato*" OR taro* OR turnip* OR ulluc* OR "water chestnut*" OR wasabi* OR yacón OR yacon OR yam* OR rhubarb* OR "pie plant" OR samphire* OR "bulb vegetable*" OR "stem vegetable*" OR "tuber vegetable*" OR "root vegetable*" OR "underground vegetable*")) AND (TITLE-ABS-KEY ("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*")) AND (TITLE-ABS-KEY (pa* OR "pyrrolyzidine alkaloid*" OR ta* OR "tropane alkaloid*")) AND NOT (pathogen* OR streptococcus OR listeria OR *virus* OR bacillus OR salmonella OR clostridium OR staphylococcus OR outbreak OR "foodborne disease*" OR fung* OR campylobacter OR "Escherichia coli" OR "E. coli" OR model* OR analytic* OR microbio* OR bacteri* OR virol* OR nutri* OR sweden)

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WFSR report 2020.009

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The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to inding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 12,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.