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Prioritisation of substances in **replacers of dairy and meat** for monitoring and risk assessment

RIVM letter report 2025-0163

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Colophon

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Synopsis

Prioritisation of substances in replacers of dairy and meat for monitoring and risk assessment

People ingest many different substances through food. In addition to healthy nutrients, these may include potentially hazardous substances. These substances can either occur naturally in plant- and animal-based foods, or be introduced during the production process. Eating less animal-based food and more plant-based food is good for both health and the environment. However, plant-based food can contain different substances than those found in animal-based food.

For maintaining a good health, it is important that people consume as less hazardous substances as possible. It is, therefore, important to identify which substances people in the Netherlands might consume more of if they replace milk, cheese and meat products with ready-made plant-based substitutes. The National Institute for Public Health and the Environment (RIVM) has therefore compiled an inventory of these substances.

In all, the RIVM identified 33 substances, or groups of substances, that can be found in the most commonly consumed dairy and meat substitutes. They include heavy metals and mycotoxins. A large proportion of these substances can also be found in dairy and meat products.

For 12 substances, or groups of substances, it is important to determine whether consumption levels could become too high when dairy and meat products are substituted with ready-made plant-based substitutes. For 10 substances, it was not possible to determine this, due to a lack of information. The assessment was possible for two substances: cadmium and lead. The results indicate that the effect of these products on the total quantity of cadmium and lead that people consume through food is small.

The RIVM only investigated substances that people might consume too much if they were to replace animal products with plant-based ones. People might also ingest less of some other harmful substances in this situation, but this was not examined. The RIVM conducted this research at the instigation of the Netherlands Food and Consumer Product Safety Authority (NVWA).

Keywords: protein transition, dairy replacers, meat replacers, contaminants, heavy metals, mycotoxins, plant toxins, process contaminants

Publiekssamenvatting

Schadelijke stoffen in vervangers van zuivel en vlees in kaart gebracht voor monitoring en risicobeoordeling

Via voedsel krijgen mensen veel verschillende stoffen binnen. Naast gezonde voedingsstoffen zijn dat schadelijke stoffen. Deze stoffen zitten van nature in plantaardig en dierlijk voedsel, of zijn er door het productieproces in gekomen. Voor het klimaat en de gezondheid is het goed om minder dierlijk en meer plantaardig voedsel te eten. Een aandachtspunt is wel dat plantaardig voedsel andere schadelijke stoffen kan bevatten dan dierlijk voedsel.

Voor hun gezondheid is het belangrijk dat mensen niet teveel schadelijke stoffen binnenkrijgen. Het is daarom belangrijk om te weten welke stoffen mensen in Nederland meer kunnen binnenkrijgen als ze melk-, kaas- en vleesproducten vervangen door kant-en-klare plantaardige vervangers. Het RIVM inventariseerde daarom deze stoffen.

Het RIVM vond in totaal 33 (groepen van) stoffen die kunnen zitten in zuivel- en vleesvervangers die mensen het meeste eten. Dat zijn bijvoorbeeld zware metalen en schimmelgifstoffen. Een groot deel van deze stoffen kan ook in zuivel en vlees zitten.

Voor 12 (groepen van) stoffen is het belangrijk om te kijken of mensen er niet te veel van binnen krijgen als ze melk- en vleesproducten vervangen door kant-en-klare plantaardige vervangers. Voor 10 stoffen was dat nu niet mogelijk omdat er te weinig informatie over is. Voor twee stoffen, cadmium en lood, kon dat wel. Daaruit blijkt dat het effect van deze producten op de totale hoeveelheid cadmium en lood die mensen via voeding binnenkrijgen, klein is.

Het RIVM onderzocht alleen welke stoffen mensen mogelijk te veel kunnen binnenkrijgen als ze dierlijke producten vervangen door plantaardige. Mensen kunnen daarbij ook van sommige schadelijke stoffen minder binnenkrijgen, maar daar is niet naar gekeken. Het RIVM deed dit onderzoek in opdracht van de Nederlandse Voedsel- en Warenautoriteit (NVWA).

Kernwoorden: eiwittransitie, zuivelvervangers, vleesvervangers, contaminanten, zware metalen, mycotoxinen, plantentoxinen, procescontaminanten

Contents

Summary

The aim of this report was to investigate whether the consumption of industrially produced dairy and meat replacers increases the dietary exposure to certain hazardous substances in order to prioritise substances for monitoring and risk assessment. For this, three questions were answered discussing 1) representative consumption amounts of industrially produced dairy and meat replacers for children aged 1 – 3 years and adults in the Netherlands, 2) the possible presence of hazardous substances in industrially produced dairy and meat replacers, and 3) the prioritisation of these substances for future monitoring and risk assessment.

The Dutch Food Consumption Survey 2019-2021 shows that the most frequently consumed industrially produced dairy replacers are replacers of milk and milk drinks, yoghurt and cheese. The major ingredients of these products were almond, coconut (oil), oat, pea, rice, soy, cashew nut, starch and water. Regarding meat replacers, replacers of dinner meat, pâté and slices were most frequently consumed. The major ingredients of these products were pea, soy, wheat, vegetable oil (undefined, soy or sunflower), egg protein and water. A minority of consumers used these replacers. Current consumption statistics of the total population, who may consume dairy and meat replacers once in a while, is an underestimation for frequent consumers of these products (consumers only). Therefore, we only looked at the consumption portions of consumers of these dairy and meat replacers and not at consumption statistics of the total population. Consumed portions of consumers only were in the same magnitude of order as portions of dairy and meat.

In these most frequently consumed industrially produced dairy and meat replacers, 33 (groups) of substances (amongst others mycotoxins, plant toxins, (heavy) metal(loid)s, persistent organic pollutants and process contaminants) were identified that may be present.

In order to make a prioritisation for future monitoring and risk assessment, the list with 33 (groups) of substances was further narrowed down to obtain the priority substances for which a dietary exposure assessment is needed. This resulted in twelve (groups of) priority substances. For six of them, i.e. alternariol (AOH) and alternariol monomethyl ether (AME), aflatoxins, T-2 and HT-2 toxins, deoxynivalenol (DON) and metabolites, erucic acid and polycyclic aromatic hydrocarbons (PAHs), additional sensitive chemical analyses in dairy and/or meat replacers are needed to obtain reliable concentration data before they can be considered for an exposure assessment. For four other substances, i.e. glycidyl esters (GEs), mineral oil aromatic hydrocarbons (MOAH), acrylamide and inorganic arsenic (iAs), the dietary exposure could not be assessed within the current project due to the lack of recent exposure data.

For two substances, i.e. lead and cadmium, sufficient data were available to assess the dietary exposure. Dietary exposure to cadmium

and lead was calculated via the current diet (baseline) and in the case that the consumption of dairy and/or meat was fully replaced with industrially produced replacers. Substitution of dairy and meat with industrially-produced dairy and meat replacers showed that this may have a limited impact on the dietary exposure to cadmium and lead. It should be noted that the dietary exposure to both substances is likely overestimated in the substitution scenarios.

The priority of certain substances more typical for industrially-produced plant-based replacers (enniatins, isoflavones, lectins and protease inhibitors), for which higher dietary exposures could be expected when a shift towards more plant-based diet takes place, could not be assessed due to the lack of a toxicological reference value (TRV) and/or an analytical method. For these substances, analytical methods and TRVs need to be developed to before being able to assess whether a risk assessment would be needed. Further, industrially-produced plant-based replacers are an innovative field and many new products based on different ingredients are to be expected, each having their own possible impact on dietary exposure to substances. Therefore, changes in replacers on the market can lead to other substances that require attention in the future.

1 Introduction

A shift towards a diet containing more plant-based proteins and less animal-based proteins is beneficial for climate and health. In 2023, the Health Council of the Netherlands published an advisory report titled ‘A healthy protein transition’. In this advisory report they examined the health consequences of a shift to a diet consisting of 60% plant-based and 40% animal-based proteins. The Health Council concluded that “the shift to a diet with 60% plant-based and 40% animal-based proteins is beneficial for the health of most Dutch people” as it better aligns with the Dutch dietary guidelines. One of the recommendations of the report was therefore to implement policy measures to progress to a shift to 40% animal and 60% plant-based proteins for the entire Dutch population. Potential food safety issues associated with this shift were not addressed (Health Council, 2023). During the course of the research described in the current RIVM report, the Health Council published in 2025 the new dietary guidelines for healthy nutrition in which a higher consumption of pulses and unsalted nuts and peanuts and a lower consumption of (red) meat and processed meat products was advised (Health Council, 2025a). In one of the background reports of the new guidelines, they addressed the presence of lectins (pulses), mycotoxins (pulses, nuts and peanuts), isoflavones (soy), acrylamide (nuts and peanuts) and polyaromatic hydrocarbons (PAHs) in plant protein sources (Health Council 2025b). In this background report, they concluded that a shift towards more plant-based proteins could lead into a diminished exposure to per and poly fluor alkyl substances (PFAS; present in dairy, meat and fish), dioxins and dioxin-like polychlorinated biphenyls (PCBs; present in dairy, meat and fish), methyl mercury (present in fish) and inorganic arsenic (present in fish). It was also concluded that attention is needed for mycotoxins (soy and nuts) and isoflavones (in soy) and cyanogenic glycosides (linseeds), acrylamide (roasted nuts) and PAHS (roasted nuts). Grains, which were also important protein sources, and vegetables were not specifically addressed in the background report, and will be presented in another report. In addition, the Health Council did not specifically address industrially processed dairy and meat replacers. The consumption of these types of replacers may also lead to exposure to other chemical substances or to different exposure levels than via the consumption of dairy and meat (Banach et al., 2022).

To protect consumers, especially higher exposures to toxicologically relevant substances due to the consumption of (industrially) produced dairy and meat replacers are of interest. The Office for Risk Assessment & Research (BuRO) therefore requested RIVM to investigate whether the consumption of dairy and meat replacers increases the dietary exposure to certain hazardous substances in order to prioritise substances for monitoring and riskassessment. Box 1 gives a description of what types of replacers were considered in the current study.

Box 1 Scope of the study
In this report, dairy replacers are defined as industrially produced composite foods which are positioned on the market as replacer of dairy, or which consumers have adopted as replacer of milk and milk products (e.g. replacer of chocolate milk, cream, cheese, or yoghurt). Meat replacers are defined as industrially produced composite foods which are positioned on the market as replacer of meat or processed meat, such as vegetarian burgers, filet, sausage and ham. The focus in this report is on plant-based dairy and meat replacers. Therefore, egg replacers, or mycoprotein-based or milk-based meat replacers are not included, since consumption of these replacers is low in the Netherlands. Further, the nutritional value (i.e. protein content or vitamins), microbiological risk and allergenicity are not considered. Simple foods consisting of one ingredient, such as legumes and nuts, are also not included.

The report focused on substances for which the exposure will increase when consuming replacers instead of dairy and meat. Substitution of dairy and meat may also result in a lower exposure to certain substances, e.g. to substances mainly occurring in dairy and/or meat. However, a lower exposure to chemicals will not lead to an increased risk and is therefore not considered in this report.

This letter report will discuss three questions:
1) What are representative consumption amounts of dairy and meat replacers for children aged 1 – 3 years and adults in the Netherlands?
2) Which substances are found in dairy and meat replacers that may be of concern? This question addresses the (possible) presence of hazardous substances.
3) Which of those substances may pose a health risk? This question addresses the prioritisation of substances for risk assessment.

Chapters 2 to 4 address the answers to the three questions as well as the methods used. Chapter 5 describes an exposure assessment for the prioritised substances that may pose a risk due to the consumption of dairy and/or meat replacers. Conclusions are described in Chapter 6.

2 Representative consumption amounts of dairy and meat replacers for children ages 1-3 years and adults in the Netherlands

In this chapter, representative consumption amounts of dairy and meat replacers are presented. These consumption amounts are needed to perform point estimates of dietary exposure to substances via replacers of dairy and meat. These point estimates were used in the prioritisation process of substances described in Chapter 4.

2.1 Mean and P95 consumption of dairy and meat replacers in the Netherlands

The current report focuses on the chronic consumption of dairy and meat replacers. The reason for this is that the report focuses on a shift in diet, which will mean a shift in exposure on the long-term.

According to StatLine RIVM (RIVM 2025), the mean chronic consumption of dairy and meat replacers for the total population (1-79 years) was very low, comparable to one sip (13.7 g dairy replacers) and half a bite (5.0 g meat replacers) per day, respectively, in the most recent Dutch National Food Consumption Survey (DNFCS) 2019-2021. The mean contribution of plant-based protein to the total protein intake of Dutch people aged 17-69 was stable between 2007-2010 and 2019-2021 (46 and 42% for children and adults, respectively) (van Rossum et al., 2023). However, the consumption of plant-based replacers can be high for certain individuals. Therefore, this report focuses on consumers of replacers only (see Box 2 for an explanation).

Box 2 Consumers only
Dairy and meat replacers are only consumed by a small fraction of the total population. Therefore, consumption statistics of the replacers by the total population is very low. The prioritisation of substances in dairy and meat replacers for risk assessment focused therefore on those subjects that consume these replacers, because they will have the highest exposure to substances via replacers. These subjects are called ‘consumers only’ and are defined as survey participants that consumed at least one product of a specific group of replacers on at least one of the two consumption days included in the food consumption survey (recall days).

2.2 Consumption amounts of dairy replacers

The chronic consumption amounts of replacers of milk and milk drinks, yoghurt, cheese, ice cream, desserts, cream and coffee cream were recently reported in a Front Office advisory report (2025). Those amounts were derived from the DNFCS 2019-2021 (van Rossum et al., 2023) and calculated for consumers only of these replacers. According to StatLine RIVM (RIVM, 2025), milk and milk drink, yoghurt and cheese are most frequently consumed. Consequently their replacement with plant-based alternatives could have the largest impact on exposure to certain hazardous substances. Therefore, this report focusses on these dairy replacers. For risk assessment purposes, 1- to 3-year-olds and adults were selected. The consumption amounts of dairy replacers were calculated for 703 children aged 1 – 3 years resulting in maximally 1406 recall days and for 1747 adults (18 – 79 years) resulting in maximally 3494 recall days. Table 2.1 presents the number of consumption days and the consumed amounts for milk, milk drink, yoghurt and cheese replacers for the two age groups. The consumption days for these replacers ranged from 0 to 86 days for the 1- to 3-year-olds and from 3 to 140 days for adults.

A reliable 95th percentile (P95) for the chronic consumption could only be calculated for milk and milk drink replacers (P95: 535 g) for adults (EFSA, 2011a). Therefore, P95 consumption statistics of milk and milk drinks by 1- to 3-year-olds and of cheese and yoghurt by both age groups were used as a proxy for the consumption of their replacers. This was based on the assumption that consumers will replace these dairy products with their dairy replacer counter parts. These consumption statistics are also presented in Table 2.1. The consumption days ranged from 428 to 1222 for 1- to 3-year-olds and from 1332 to 2472 for adults. The mean consumption of dairy was in the same magnitude of order as that of dairy replacers underlining the reasonableness of the use of consumption statistics for dairy for dairy replacers.

Table 2.1 Chronic consumption statistics (mean and P95, consumers only) in grams for dairy replacers and dairy by Dutch children from 1 – 3 years old and adults (18 to 79 years).

Age group	**Consumption statistics of dairy replacers**[a]				**Consumption statistics of dairy**[b]			
	Milk and milk (drink) replacers				*Milk and milk drinks*			
	Consumption days	Participants (N)	Mean	P95	Consumption days	Participants (N)	Mean	P95
1-3 years	86	52	253	-[c]	1222	651	337	670
adults	140	92	223	536	1893	1135	314	772
	Yoghurt replacers				*Yoghurts*			
	Consumption days	Participants (N)	Mean	P95	Consumption days	Participants (N)	Mean	P95
1-3 years	11	8	120	-	428	313	134	288
adults	54	43	197	-	1332	883	218	436
	Cheese replacers				*Cheeses*			
	Consumption days	Participants (N)	Mean	P95	Consumption days	Participants (N)	Mean	P95
1-3 years	3	3	19	-	790	512	24	58
adults	6	6	29	-	2472	1504	51	128

[a] Consumption statistics based on Front Office advisory report (2025).

[b] RIVM (2025) https://statline.rivm.nl/portal.html?_la=nl&_catalog=RIVM&tableId=50110NED&_theme=103

[c] Statistics presented as '-': For a reliable P95 the default minimum number of participants is 60 (EFSA, 2011). See Use of the EFSA Comprehensive European Food Consumption Database in Exposure Assessment.

2.3 Consumption amounts of meat replacers

The consumption amounts of meat replacers were also obtained from StatLine RIVM (RIVM, 2025). Meat replacers were split into replacers of hot processed meat (processed meat consumed for dinner, i.e. hamburger, breaded meat products) and of cold processed meat (cold cuts, usually consumed as sandwich toppings) in the DNFCS 2019-2021. An extract of the food consumption data was obtained for the two age groups. Table 2.2 presents the number of consumption days and consumption amounts for the two types of meat replacers, again for consumers only. For children from 1 – 3 years old, the number of consumption days for hot processed meat replacers was 49 (4.5%) and of cold processed meat replacers 21 (1.5%). For adults, these numbers were 194 (2.7%) and 32 (0.9%), respectively.

A reliable P95 chronic consumption amount could only be calculated for the consumption of hot processed meat replacers for adults (EFSA, 2011a). As was done for dairy replacers, as a proxy, the consumption statistics for the conventional meat counter parts, i.e. hot processed meat and cold processed meat, were used. For children from 1 – 3 years old, the number of consumption days was 472 (34%) for hot processed meat and 612 (44%) for cold processed meat. For adults, these numbers were respectively 945 (27%) and 1790 (51%). The mean consumption statistics for hot and cold processed meat products were in the same magnitude of order as those of the replacers. Therefore, the consumption statistics of hot and cold processed meat products were assumed to reflect the consumption statistics of meat replacers.

Table 2.2 Chronic consumption statistics (mean and P95, consumers only) in grams of processed meat replacers and processed meat products by Dutch children aged 1 – 3 years and adults (18 – 79 years).

Age group	**Consumption statistics of meat replacers**[a]				**Consumption statistics of processed meat products**			
	Hot processed meat replacers				*Hot processed meats*			
	Consumption days	Participants (N)	Mean	P95	Consumption days	Participants (N)	Mean	P95
1-3 years	49	42	42	-[b]	472	370	53	113
adults	194	162	85	190	945	779	94	208
	Cold processed meat replacers				*Cold processed meats*			
	Consonsumption days	Participants	Mean	P95	Consumption days	Participants	Mean	P95
1-3 years	21	20	17	-	612	440	22	57
adults	32	23	39	-	1790	1181	41	100

[a] RIVM (2025) https://statline.rivm.nl/portal.html?_la=nl&_catalog=RIVM&tableId=50110NED&_theme=103

[b] Statistics presented as '-': For a reliable P95 the default minimum number of participants is 60 EFSA (2011). See Use of the EFSA Comprehensive European Food Consumption Database in Exposure Assessment.

3 Substances in dairy and meat replacers that may be of concern

This chapter describes the toxicological relevant substances that potentially can be present in dairy and meat replacers. These substances can be present for several reasons:

- They can be directly added to replacers, such as food additives;
- They can occur as a contaminant in ingredients of replacers; and/or
- They can be formed during processing, such as heat treatment, of replacers.

This chapter describes the inventory of substances that potentially can be present in dairy and meat replacers. To gain insight into the contaminants that might be present in their ingredients an overview of the ingredients listed on food labels was made. Section 3.1 describes the method to identify these ingredients. Sections 3.2 and 3.3 describe the ingredients in respectively dairy and meat replacers. Substances related to the ingredients of dairy and meat replacers are described in Section 3.4.

3.1 Method to identify ingredients

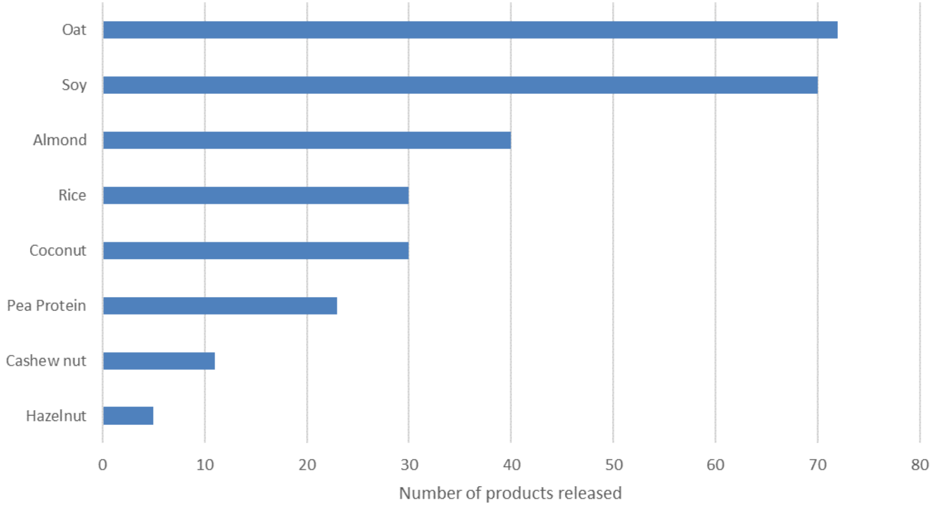
Mintel's Global New Product Database (GNPD) and the Branded Food Label Database (LEDA) were used to gain insight into the composition of dairy and meat replacers. Mintel's GNPD reports new products that have been launched on the Dutch market and was accessed between 5 and 12 February 2024. LEDA gives an overview of products that were on the market in 2023 and a data extraction dated 27 December 2023 was used. First the characteristic ingredient, which is the ingredient by which a variant of a dairy replacer can be distinguished, e.g. soy drink, oat drink, soy-based alternative for yoghurt, was determined for each product on the market. Next, the products with the most frequently occurring characteristic ingredients were selected. Finally, the full ingredient lists of the selected products were used to identify toxicological relevant substances.

3.2 Characteristic ingredients of dairy replacers

Mintel's GNPD was searched using the characteristic ingredient of a dairy replacer For this, ingredient declarations of new replacers released between 2019 and 2023 on the Dutch market were checked. It was assumed that these five years would give a good representation for replacers that were available on the market early 2024. The number of new replacers released between 2019 and 2023 was summed per characteristic ingredient.

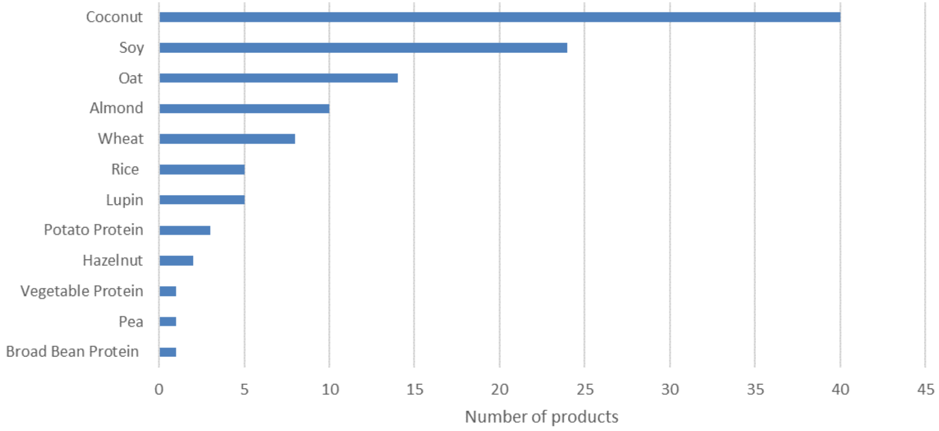
Oat and soy were the most frequently used characteristic ingredients in milk (drink) replacers, followed by almond, rice, coconut and pea. Only a few new milk (drink) replacers contained cashew nut and hazelnut (Figure 1). These products were considered as niche products that do not largely contribute to chronic exposure and, therefore, were not taken into account. The full ingredient list of milk (drink) replacers containing almond, coconut, oat, pea, rice and soy was used to identify toxicological relevant substances (Section 3.4).

Figure 1 Characteristic ingredients in milk (drink) replacers released on the Dutch market between 2019 and 2023. Data were obtained from Mintel's GNPD.



Regarding yoghurt replacers, coconut was the predominant characteristic ingredient, followed by soy, oat and almond. Less than 10 new products contained wheat, rice, lupin, potato, hazelnut, pea or broad bean as characteristic ingredient (Figure 2). Therefore, this report focusses on yoghurt replacers based on coconut, soy, oat and almond. The full ingredient list of yoghurt replacers containing these characteristic ingredients was used to identify toxicological relevant substances (section 3.4).

Figure 2 Characteristic ingredients in yoghurt replacers released on the Dutch market between 2019 and 2023. Data were obtained from Mintel's GNPD.



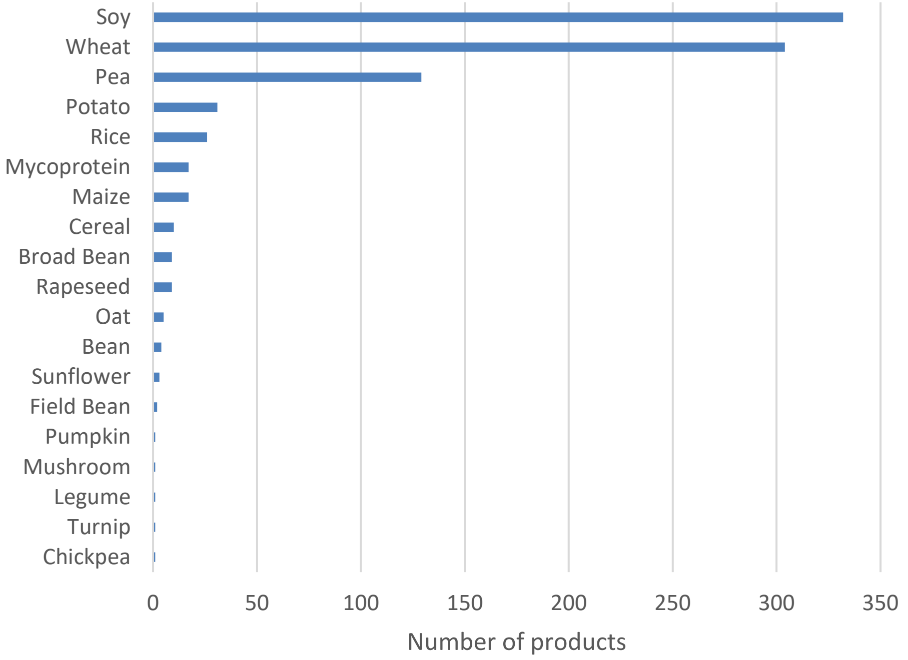
Cheese replacers were not found in Mintel's GNPD. Instead, the LEDA was used to search for characteristic ingredients. LEDA showed that the characteristic ingredients in cheese replacers were coconut oil, cashew nut, or almond. The full ingredient lists of cheese replacers based on coconut oil, cashew nut, and almond were used to identify toxicological relevant substances (Section 3.4).

3.3 Characteristic ingredients of meat replacers

Plant-based proteins are the characteristic ingredients of meat replacers. Soy protein and wheat protein are the most commonly used proteins, followed by pea protein (Figure 3). Plant-based protein can be added to the meat replacers as native proteins (e.g. proteins isolated or concentrated from a protein source) or as texturised proteins (proteins subjected to a type of processing using heating, resulting in a fibre-like structure). Information on the type of protein used in the meat replacer, (native or textured protein), may give an indication of which contaminants may be generated during processing. Unfortunately, for the most frequently used proteins in meat replacers, the type of protein was usually not mentioned in Mintel's GNPD. Therefore, it was assumed that heating of proteins during the production process was applied.

LEDA also showed that soy, wheat and pea protein were the most frequently used proteins. In addition, LEDA showed that a combination of protein sources is very common, even up to three to four sources. Since this report focuses on chronic exposure, the three most frequently used characteristic ingredients, i.e. soy, wheat and pea proteins, were selected, because it was assumed that niche products will not largely contribute to chronic exposure. The full ingredient list of meat replacers with soy, wheat and pea proteins was used to identify relevant toxicological substances in the next section.

Figure 3 Plant-based protein sources used in meat replacers released between 2019 and 2023 on the Dutch market in 2023. Data were obtained from Mintel's GNPD.



3.4 Toxicologically relevant substances in dairy and meat replacers

In this section, toxicologically relevant substances potentially occurring in selected dairy and meat replacers are discussed.

3.4.1 *Food additives*

According to the ingredients listed on replacers belonging to the selected food groups (see above), plant-based milk and meat replacers contain food additives that are not present in their animal-based counterparts. In the EU, the presence of food additives in foods are monitored and together with the food consumption data of a wide range of European member states, the risk of the use of food additives is assessed by the European Food Safety Authority (EFSA). If a risk cannot be excluded, measures are taken (reduction of uses and/or use levels) to lower the exposure. To guarantee sufficient monitoring data, a new monitoring program will start in 2026. A monitoring plan for food additives to be monitored in the Netherlands will be prepared by the RIVM and is commissioned by the Dutch Ministry of Health, Welfare and Sport Prioritisation of food additives will be part of that plan and will be done according to the Commission's recommendation 2023/965 on the methodology for the monitoring of food additive and food flavouring intake[1]. Briefly, the prioritisation includes food additives for which 1) the intake exceeded 50% of the acceptable daily intake; and 2) an increased intake is to be expected based on presence data (using e.g. labels from databases such as LEDA) and consumption data. Since that approach covers food additives in dairy and meat replacers, food additives were not included in the prioritisation of substances in dairy and meat replacers for risk assessment.

3.4.2 *Plant protection products*

Like all other types of foods, the ingredients of plant-based dairy and meat replacers are likely to contain pesticide residues. These levels may differ to some degree from the levels in meat and dairy products. Accordingly, it is conceivable that the replacement of dairy and meat with plant-based substitutes could alter the exposure of consumers to pesticides, and thus pesticides could have been considered for inclusion in the current study. However, under EU legislation, the levels of pesticide residues in food commodities are monitored and, in combination with food consumption data from various subpopulations from a wide range of European member states, the safety of pesticide residue levels in both raw and processed foods such as dairy and meat replacers is assessed. The risk assessment for plant protection product residues in dairy and meat replacers is thus already regulated under current EU legislation and, therefore, this class of chemicals was not included in the current prioritisation of substances in dairy and meat replacers for risk assessment.

3.4.3 *Contaminants*

Contaminants (natural occurring, environmental and due to processing) that can be present in dairy and meat replacers were determined by the list of ingredients, EFSA evaluations, existing maximum levels (MLs) included in Regulation 2023/915[2] and/or other available literature

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[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023H0965

[2] Consolidated TEXT: 32023R0915 — EN — 01.01.2025

(Banach et al., 2022; EFSA, 2008; EFSA, 2010a; EFSA, 2012a; EFSA, 2012b; EFSA, 2012c; EFSA, 2013; EFSA, 2014; EFSA, 2015a; EFSA, 2015b; EFSA, 2016a; EFSA, 2016b; EFSA, 2016c; EFSA, 2016d; EFSA, 2016e; EFSA, 2017a; EFSA, 2017b; EFSA, 2017c; EFSA, 2018a; EFSA, 2018b; EFSA, 2018c; EFSA, 2019; EFSA, 2020a; EFSA, 2020b; EFSA, 2020c; EFSA, 2020d; EFSA, 2022; EFSA, 2023; EFSA, 2024; EFSA, 2025a; EFSA, 2025b; EFSA, 2025c; EFSA, 2025d).

This resulted in the following (group) of substances:

Mycotoxins

- *Alternaria* toxins, i.e. altenariol (AOH), alternariol methyl ether (AME), tentoxin (TEN) and tenuazonic acid (TeA)
- Aflatoxins (AFB_1, AFB_2, $AFG_1$and AFG_2)
- Deoxynivalenol (DON) and metabolites
- Enniatins (A, A1, B, B1)
- Ergot alkaloids
- Fumonisins (FB_1, FB_2, FB_3 and FB_4)
- Ochratoxin A (OTA)
- T-2 and HT-2 toxins
- Zearalenone (ZEA) and metabolites

Phytotoxins

- Cyanogenic glycosides
- Δ9-tetrahydrocannabinol & Δ8-tetrahydrocannabinol
- Glyco alkaloids
- Erucic acid
- Lectins
- Tropane alkaloids
- Protease inhibitors
- Isoflavones

Metals and metalloids (further referred to as heavy metals)

- Inorganic arsenic (iAs)
- Cadmium (Cd)
- Lead (Pb)
- Inorganic mercury (iHg)
- Nickel (Ni)

Processing contaminants

- Acrylamide
- Advanced glycation end products (AGEs; including argpyrimidine, carboxyethyl-lysine (CEL), Nε-carboxymethyllysine (CML), methylglyoxal hydroimidazolones (MG-H), glyoxal hydroimidazolones (GH) and pentosidine)
- Glycidyl fatty acids (GEs)
- 3-Monochloropropanediol (3-MCPD) and fatty acid esters
- Polycyclic aromatic hydrocarbons (PAHs)

Others

- Dioxins
- Polychlorinated biphenyls (PCBs)
- Perchlorate
- Per and polyfluoro alkyl substances (PFAS)
- Nitrate and nitrite[3].
- Mineral oil saturated hydrocarbons (MOSH)
- Mineral oil aromatic hydrocarbons (MOAH)

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[3] Nitrite is generated out of nitrate and therefore the two ions commonly occur together.

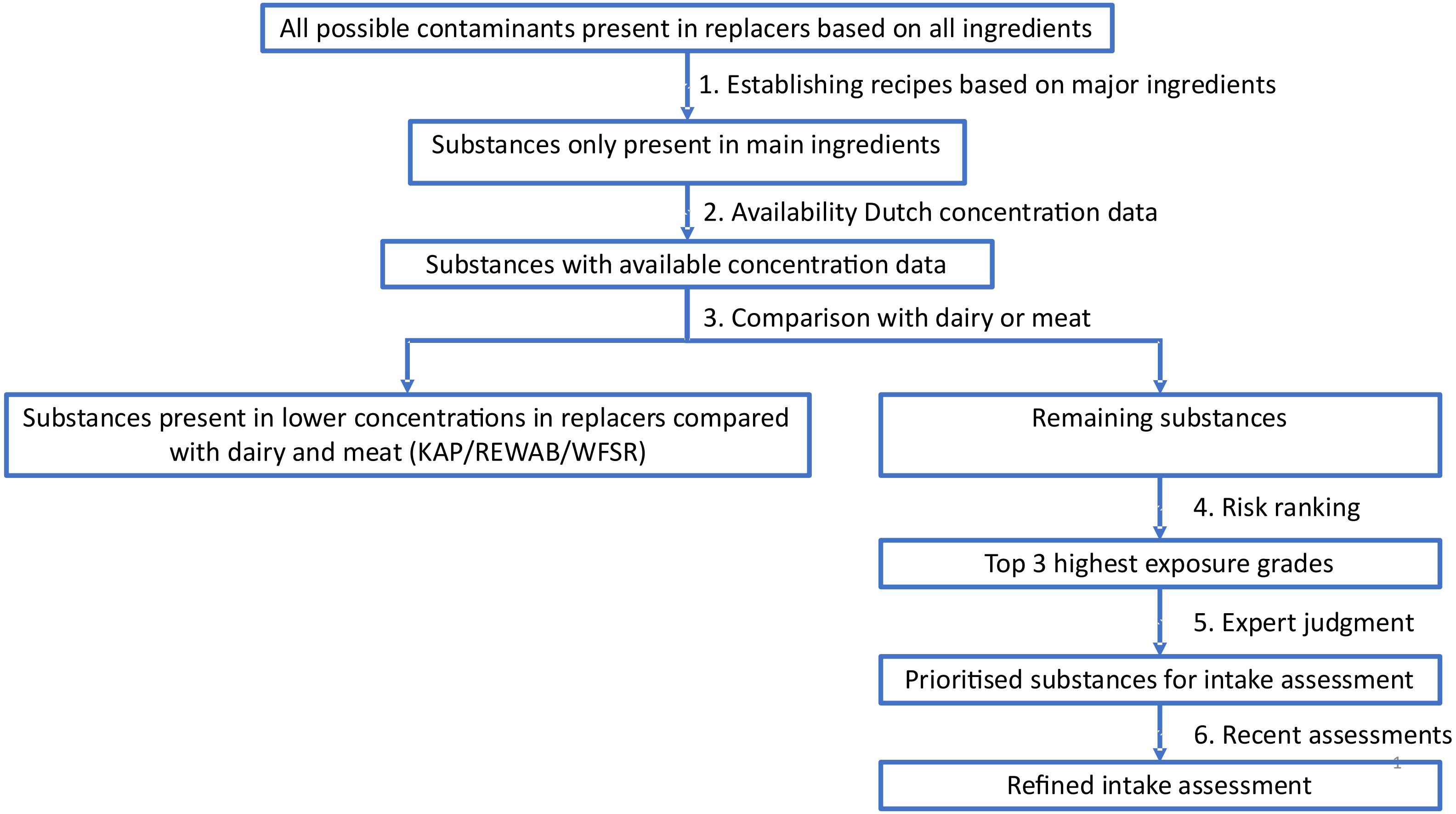
4 Prioritisation of substances with a possible health risk in dairy and meat replacers for risk assessment

In the previous chapter, a list of known toxicologically relevant substances in dairy and meat replacers was presented. The presence of these substances themselves does not necessarily result in a health risk, since the exposure determines the risk. Therefore, first an exposure assessment is needed in order to perform a risk assessment. Since performing an exposure assessment is laborious and expensive, it is not feasible to perform these for all identified substances within the budget boundaries of this project. Therefore the list was narrowed down to obtain the priority substances that may pose a health risk and for which an exposure assessment can be performed. This chapter describes the procedure to narrow down this list. After each step the remaining substances are presented. Appendix 1 provides per prioritisation step a full overview of omitted and remained substances.

4.1 Prioritisation process

A step-wise approach was followed for the prioritisation of the substances, which is summarized in Figure 4. In the first step, described in Section 4.2, substances that can be potentially present in the major ingredients of dairy and meat replacers were identified based on standard recipes for dairy and meat replacers. In the second step, described in Section 4.3, the availability of Dutch concentration data was used to determine which substances could be included further in the prioritisation process. In the third step (Section 4.4), the concentrations of substances in the replacers were compared with those in dairy and meat. If the concentrations were lower in replacers than in their animal-based counterparts, the substances were not prioritised since the consumption of replacers would then not lead to an extra risk compared to the consumption of products from animal origin. In the last steps, the remaining substances were subjected to risk ranking (Section 4.5), expert judgment (Section 4.6) and the availability of recent Dutch dietary exposure assessments was taken into account (Section 4.7). The prioritisation steps and results of the prioritisation process are discussed in Section 4.8. Finally, Section 4.9 summarises the main conclusions of the prioritisation process.

Figure 4 The process to prioritize substances for an exposure assessment based on available information and resources



4.2 Step 1: Prioritisation based on the major ingredients

Mintel's GNPD and LEDA revealed that the characteristic ingredients in dairy and meat replacers were almond, cashew nut, coconut (oil), oat, pea, rice, soy, and wheat (see Chapter 3). Using the information from the latest DNFCS, Mintel's GNPD, LEDA and CPAP (Conversion model Primary Agricultural Products, a model that splits consumed foods into their ingredients; Van Dooren, 1995), standard recipes were developed based on the major ingredients used in replacers. Subsequently, these standard recipes were used to identify substances potentially occurring in the major ingredients of dairy and meat replacers.

Table 4.1 shows the standard recipes for the three food groups of dairy replacers included in the prioritisation (milk (drink) replacers, yoghurt replacers, cheese replacers) and three food groups of meat replacers (one hot meat replacer (for dinner meat) and two for cold meat replacers (pâté and slices)). The standard recipes mainly differed in the type of the characteristic ingredient (e.g. peas, soy, wheat, etc.), edible fat (for meat replacers), and water. For each type of replacer, it was assumed that the standard recipes only varied in the type of characteristic ingredient, not in the amount. For example, milk (drink) replacers consisted of 91% water and 9% characteristic ingredient, being almond, coconut, oat, pea, rice or soy.

Table 4.1 Major ingredients with their percentages for three standard recipes of dairy replacers and three standard recipes of meat replacers

Ingredient	**Percentage (%)**
Dairy replacers	
Milk (drink) replacer	
Almond, coconut, oat, pea, rice or soy	9
Water	91
Yoghurt replacer	
Almond, coconut, oat or soy	11
Water	88
Cheese replacer	
Almond, cashew nut or coconut oil	21
Starch (potato/corn)	19
Water	60
Meat replacers	
Dinner meat replacers	
Pea, soy, or wheat	18
Vegetable oil	7
Water	75
Pâté replacer	
Pea, soy, or wheat	7
Vegetable oil	20
Water	61
Miscellaneous minor ingredients[a]	12
Slices	
Pea, soy, or wheat	20
Egg protein	10
Soy oil	3
Sunflower oil	21
Water	47

[a] Pâté replacers are heterogenous products containing a lot of other minor ingredients

4.2.1 *Substances potentially occurring in ingredients of the standard recipes*

The long list of substances presented in Section 3.4.3 was narrowed down by only selecting the substances that are associated with the major ingredients of the standard recipes for dairy and meat replacers as presented in Table 4.1. Due to heat-treatment (e.g. baking of meat replacers before consumption), processing contaminants may be formed. These were included as well. This step resulted in a list of 33 (grouped) contaminants (see Table 4.2 and Appendix 1).

Table 4.2 Overview of substances associated with major ingredients of the standard recipes of dairy and meat replacers

Ingredient			**Substances**				**Replacer**
Dairy replacers							
Soy	*Alternaria* toxins	Cd Isoflavones	Ni Lectins	OTA Pb	Perchlorate Protease inhibitors		Milk (drink) replacer Yoghurt replacer
Almond	Acrylamide Aflatoxins	*Alternaria* toxins Cd	Cyanogenic glycosides Ni	Pb			Milk (drink) replacer Yoghurt replacer Cheese replacer
Oat	Acrylamide Aflatoxins *Alternaria* toxins	Cd DON Ergot alkaloids	iAs Lectins Ni	Pb OTA	Perchlorate T-2 and HT-2	Tropane alkaloids ZEA	Milk (drink) replacer Yoghurt replacer
Pea	Cd Lectins	Ni Nitrate and nitrite	Pb Perchlorate	PFAS Protease inhibitors			Milk (drink) replacer
Rice	Acrylamide Aflatoxins *Alternaria* toxins	Cd iAs	Lectins MOSH MOAH	Ni Pb	Perchlorate PFAS	T-2 and HT-2 ZEA	Milk (drink) replacer
Coconut	Cd Ni	Pb					Milk (drink) replacer Yoghurt replacer
Water	Cd iAs	iHg Ni	Nitrate and nitrite Pb	Perchlorate PFAS			Milk (drink) replacer Yoghurt replacer Cheese replacer
Coconut oil	3-MCPD Cd	GEs MOSH MOAH	PAHs Pb	PCBs Dioxins			Cheese replacer
Cashew	Acrylamide Aflatoxins	Cd Ni	Pb				Cheese replacer

Ingredient	**Substances**						**Replacer**
Starch (potato/corn)	Acrylamide Aflatoxins (corn) *Alternaria* toxins (corn)	Cd DON (corn) Enniatins (corn)	Fumonisins (corn) Glycoalkaloids (potato) iAs (corn)	Lectins (corn) Ni Pb	Perchlorate Tropane alkaloids (corn)	T-2 and HT-2 (corn) ZEA (corn)	Cheese replacer
Industrial processing	AGEs Acrylamide						Milk (drink) replacer Yoghurt replacer
Meat replacers							
Soy	*Alternaria* toxins Cd	Isoflavones Lectins	Ni OTA	Pb Perchlorate	Protease inhibitors		Dinner meat replacer Pâté replacer Slices
Wheat	Acrylamide Aflatoxins *Alternaria* toxins	Cd DON and metabolites Enniatins	Ergot alkaloids iAs Lectins	MOSH MOAH Ni OTA	Pb Perchlorate PFAS	T-2 and HT-2 Tropane alkaloids ZEA	Dinner meat replacer Pâté replacer Slices
Pea	Cd Lectins	Ni Nitrate and nitrite	Pb Perchlorate	PFAS Protease inhibitors			Dinner meat replacer Pâté replacer Slices
Vegetable oil	3-MCPD *Alternaria* toxins Cd	GEs Erucic acid (rapeseed oil) MOSH MOAH	Ni OTA	Pb PAHs	PCBs Dioxins Perchlorate	PFAS T-2 and HT-2	Dinner meat replacer Pâté replacer

Ingredient	**Substances**						**Replacer**
Water	Cd iAs	iHg Ni	Nitrate and nitrite Pb	Perchlorate PFAS			Dinner meat replacer Pâté replacer Slices
Egg protein	Cd Ni	Pb PCBs Dioxins	PFAS				Slices
Soy oil	3-MCPD *Alternaria* toxins	Cd GEs	MOSH MOAH OTA	PAHs Pb	PCBs Dioxins Perchlorate		Slices
Sunflower oil	3-MCPD *Alternaria* toxins Cd	GEs MOSH MOAH	Ni OTA	PAHs Pb	PCBs Dioxins Perchlorate	PFAS T-2 and HT-2	Slices
Industrial processing	Acrylamide	AGEs	PAHs				Dinner meat replacer
Home preparation	Acrylamide	AGEs	PAHs				Dinner meat replacer

Abbreviations substances: 3-MCPD: 3-monochloropropane-1,2-diol; Cd: cadmium; deoxynivalenol (DON) and metabolites (3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside); GEs: glycidyl fatty acids; iAs: inorganic arsenic; iHg: mercury; MOAH: mineral oil aromatic hydrocarbons; MOSH: mineral oil saturated hydrocarbons; Ni: nickel; OTA: ochratoxin A; PAHs: polycyclic aromatic hydrocarbons; Pb: lead; PCBs: polychlorinated biphenyls; PFAS: per and polyfluoro alkyl substances; ZEA: zearalenone.

4.3 Step 2: Substances with available Dutch concentration data

In the second step, out of the 33 contaminants only those were included if concentration data relevant for replacers on the Dutch market were available. First the data sources are described (Section 4.3.1), and then the substances for which available concentration data is available are discussed (Section 4.3.2).

4.3.1 Databases

Concentration data in replacers and/or their ingredients were obtained using measurements included in the Quality Program Agricultural Products (Kwaliteitsprogramma Agrarische Producten; KAP) database and the "*Registratie opgaven van Drinkwaterbedrijven*" (REWAB; monitoring results drinking water companies); the available data from the NVWA or new measurements performed by Wageningen Food Safety Research (WFSR).

KAP data

RIVM hosts the KAP database which contains chemical concentration data generated as part of monitoring programs for chemical food safety in the Dutch food chain. An extract (2019-2023) for the identified substances in Section 4.2 was generated for replacers of milk (drinks), yoghurt, cheese, dinner meat, pâté and slices. Additionally, an extract was generated for the identified substances in all major ingredients of the six standard recipes. As more measurements were available for nitrate in vegetables than for nitrite, this report focusses on nitrates rather than nitrites.

REWAB data

Since water is a major ingredient of dairy and meat replacers, contaminants associated with water should be taken into consideration in the prioritisation process. Therefore, an extract (2019-2023) was generated from the REWAB database (RIVM, 2024). REWAB contains the results of substances analysed by Dutch drinking water companies as part of their mandatory monitoring programs. The extract contained concentrations for cadmium (n=1236), lead (n=1237), inorganic arsenic (n=4853), nickel (n=1751), nitrate (=4996) and perchlorate (n=6). The REWAB database also contains information on nitrite. Since nitrite concentrations in Dutch drinking water is approximately 1000 times lower compared with nitrate (van den Brand et al., 2020), this report focusses on nitrate rather than nitrite.

It should be noted that considering only Dutch drinking water may cause some uncertainty in the selection procedure, since dairy and meat replacers produced outside the Netherlands will be not be produced with Dutch drinking water. However, information on contaminant concentrations in drinking water of the specific production sites are not readily available.

NVWA data

In 2021 NVWA performed a study into substances in cheese and meat replacers (excel file with data obtained via personal communication). Data in cheese replacers were obtained via WFSR, and those in meat replacers were available via KAP.

WFSR data

WFSR analysed in 2024 and 2025 several substances in 55 dairy replacers and 59 meat replacers that were bought at local supermarkets. A selection was made to obtain a good representation of the characteristic ingredients and available replacers at the Dutch market. These replacers were analysed for:

- heavy metals (Ni, Cu, (inorganic)As, Cd, (inorganic)Hg and Pb);
- processing contaminants (AGEs (Argpyrimidine, CEL, CML, GH, MG-H, pentosidine), 2-MCPD, 3-MCPD, GEs and acrylamide);
- mycotoxins (*Alternaria* toxins (AOH, AME, TEN and TeA), aflatoxins (AFB_1, AFB_2, $AFG_1$and AFG_2), OTA, fumonisins (FB_1, FB_2, FB_3 and FB_4), DON and metabolites, ZEA, T2 and HT2 toxins, enniatins and ergot alkaloids);
- MOSH and MOAH; and
- plant toxins, including tropane alkaloids (atropine, scopolamine, anisodamine, anosodine, aposcolamine, homatropine) and cyanogenic glycosides.

Appendix 2 gives a detailed description of the methods used for the analyses performed by WFSR and provides an overview of the results.

4.3.2 *Substances considered for prioritisation*

Substances were only considered for further prioritisation in step 3 when Dutch concentration data were available for the replacers or their major ingredients. Appendix 3 shows for which substances concentration data were available and the source of the data. No concentration data were available for glycoalkaloids, isoflavones, lectins, protease inhibitors, enniatins (for meat replacers), ergot alkaloids (for meat replacers) and AGEs (for meat replacers). Therefore, these substances(-product combination) were not further considered for prioritisation.

For dairy replacers, concentration data were available for heavy metals (iAs, Cd, iHg, Pb and Ni), mycotoxins (*Alternaria* toxins, aflatoxins, DON and metabolites, enniatins, ergot alkaloids, fumonisins, OTA, T-2 and HT-2 toxins, and ZEA), plant toxins (tropane alkaloids, and cyanogenic glycosides), process contaminants (acrylamide, AGEs, GEs, 3-MCPD and PAHs), and others (nitrate, perchlorate, PFAS, dioxins and PCBs). For meat replacers, the same concentration data were available, except for enniatins, ergot alkaloids and AGEs. In addition, concentration data were available for the plant toxin erucic acid, MOSH and MOAH. Therefore these substances were included in down-stream prioritisation.

4.4 Step 3: Comparison substance concentrations in dairy and meat with their replacers

In the third prioritisation step, the available concentrations of substances in dairy and meat replacers were compared with those in dairy and meat. As the consumption amounts of dairy and meat and their replacers have the same order of magnitude in consumers (see Tables 2.1 and 2.2), it was assumed that if consumers substitute dairy and meat with dairy and meat replacers they will consume these products in equal amounts. In that case, the concentrations of substances in dairy and meat can be compared with those in the replacers. Substances with higher concentrations in the replacer will then qualify for prioritisation, since lower concentrations in replacers will not be of concern in dairy and meat is to be substituted by replacers.. The methodology used for this comparison is described in Section 4.4.1 and the results in Section 4.4.2. Section 4.4.3 summarises the substances that were retained for further prioritisation.

4.4.1 *Methodology of the comparison*

For dairy and meat replacers the concentration data obtained from the sources indicated in Appendix 3 were used. For dairy and meat, concentrations were obtained from KAP for all substances.

First data from KAP and REWAB were cleaned as described in Appendix 4. Next, middle bound (MB) concentrations were assigned to foods and drinking water by substituting reported values below the level of quantification (LOQ) by half the value of the LOQ (EFSA, 2010b). The MB scenario was chosen, because the lower bound scenario (assuming that all value below LOQ equals zero) would most likely underestimate the exposure (if more sensitive methods were used more quantifiable values could be obtained). In addition, the upper bound scenario would most likely overestimate the exposure, since valued below the LOQ could also be truly zero. For some substances, the analyses were performed for a different chemical form than the form on which the risk assessment is based and hence, a conversion factor was applied (see Table 4.3).

Table 4.3 Conversion factors used to calculate the mean concentrations in dairy, meat and their replacers

Form measured	Form risk assessment	Conversion factor	Reference
tAs	iAs	0.63 (grain), 0.87 (rice drink) 1 (other foods)	EFSA 2021
tHg	iHg	1 (all foods)	EFSA 2012
Cyanogenic glycosides (HCN)	Bioavailable hydrocyanic acid	1 (almonds)	EFSA 2019

For a number of substances, the sum of exposure to a group of substances is relevant for risk assessment rather than the exposure to a single substance (i.e. aflatoxins, DON and metabolites, fuminosins, T-2 and HT-2 toxins, GEs, dioxins and dioxine-like PCBs, and NDL-PCBs). Those substances were summed according to equipotency, except for PFAS, and dioxins and DL-PCBs (see Table 4.4). For PAHs, EFSA derived a $BMDL_{10}$ for the risk assessment for four (benzo[a]pyrene, chrysene, benzo[b]fluoranthene, benz[a]anthracene; PAH4) and for eight PAHs (benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, chrysene, dibenz[a,h] anthracene and indeno[1,2,3-cd]pyrene; PAH8), respectively (EFSA, 2008). Since only concentration data for PAH4 were available, the sum of those PAHs were used in the prioritisation.

Table 4.4 Methodology used for summing substances belonging to a group

Group	**Substances included**	**Summing methodology**	**Reference**
Aflatoxins	AFB_1, AFB_2, $AFG_1$and AFG_2	Equipotency	EFSA 2020
DON and metabolites	DON, 3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside	Equipotency	EFSA 2017
Ergot alkaloids	Ergocornine, Ergocorninine, Ergocristine, Ergocristinine, Ergocryptine (a+b), a-Ergocryptinine, Ergometrine, Ergometrinine, Ergosine, Ergosinine, Ergotamine and Ergotaminine	Equipotency	EFSA 2012
Fuminosins	FB_1, FB_2, FB_3 and FB_4	Equipotency	EFSA 2018
T-2 and HT-2 toxins	T-2 and HT-2 toxins	Equipotency	EFS 2017
Tropane alkaloids	Atropine and Scopolamine	Equipotency	EFSA 2013
3-MCPDs	3-MCPD esters and 3-MCPD free	Equipotency	EFSA 2018
PFAS	Sum 20 PFAS	Relative potency	Schepens et al. (2023)
Dioxins and DL-PCBs	dl-PCBs, TCDDs and HCCDs	TEF factors	Van den Berg et al. (2005)[4]
NDL-PCBs	PCB-101, PCB-138, PCB-153, PCB-180, PCB-28 and PCB-52	Sum indicator PCBs (Equipotency)	EFSA 2005
MOSH	Sum of: MOSH >C16 to C20 MOSH >C20 to C25 MOSH >C25 to C35 MOSH >C35 to C40 MOSH >C9 to C16	Equipotency	EFSA 2023
MOAH	C10 to C50	Equipotency	EFSA 2023
PAH4	Benzo[a]pyrene, Chrysene, Benzo[b]fluoranthene Benz[a]anthracene	Equipotency	EFSA 2008

AFB_1: aflatoxine B1; AFB_2: aflatoxine B2; AFG_1: aflatoxine G1; AFG_2: aflatoxine G2; deoxynivalenol (DON) and metabolites (3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside), ZEA: zearalenone; ZEL: zearalenol; 3-MCPD: 3-monochloropropane-1,2-diol; PFAS: per- and polyfluoroalkyl substances; DL-PCBs: dioxin-like polychlorinated biphenyls; TEF: toxicity equivalency factors; NDL-PCBs: non-dioxin-like polychlorinated biphenyls; MOSH: mineral oil saturated hydrocarbons; MOAH: mineral oil aromatic hydrocarbons; PAH4: sum of 4 polyaromatic hydrocarbons.

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[4] The prioritisation was performed before EFSA published a public consultation on dioxins and PCBs (https://connect.efsa.europa.eu/RM/s/consultations/publicconsultation2/a0lTk000006Nv0X/pc1724). Therefore, the newly proposes TEFs were not taken into consideration.

If the characteristic ingredient was known, the concentrations per type of replacer and per characteristic ingredient (e.g. per soy-based milk drink replacer or oat-based milk replacer) were averaged. If the characteristic ingredient was not known, the concentrations were averaged for the whole group of replacers (e.g. meat replacers for dinner). In that case, the characteristic ingredient was denoted as 'unspecified'.

Concentrations in dairy and meat were obtained from KAP (see Appendix 4 for data handling).

If there were only concentrations in ingredients of replacers (see Appendix 3), the mean concentration in a type of replacer (e.g. soy-based milk drink replacer, pea-based meat replacer) was calculated by multiplying the mean concentration of the substance in the ingredients with the fraction of the ingredient in the replacer using the standard recipes described in Table 4.1. The mean concentrations of ingredients of dairy and meat replacers are provided in Appendix 5.

4.4.2 *Results of the comparison*

First the results for dairy replacers are presented followed by the results for the meat replacers.

Comparison between dairy replacers and dairy products

Concentration data in milk were only available for inorganic arsenic, cadmium, lead, inorganic mercury, nickel, dioxins, PCBs, PFAS, and AGEs. Therefore, only a comparison between dairy and their replacers could be made for those substances. Substances for which no comparison could be made were addressed in the next prioritisation step.

Heavy metals

Table 4.5 shows the concentrations of the metals in cow milk and in milk (drink) replacers based on almond, coconut, oat, pea, rice, and soy respectively. Compared with raw cow milk, concentrations of inorganic arsenic were higher in milk drinks based on coconut, pea and rice. Concentrations of cadmium, inorganic mercury, lead and nickel were all higher in milk (drink) replacers. Therefore, all heavy metals were included for further prioritisation, except for inorganic arsenic in almond, oat, and soy-based milk drinks.

Table 4.5 Mean concentrations of inorganic arsenic (iAs), cadmium (Cd), lead (Pb) and nickel (Ni) in cow milk and milk replacers, based on different characteristic ingredients: almond, oat, pea, soy, rice and coconut

Product	**Heavy metal concentration (mg/kg)**[c]				
ingredient	**iAs**	**Cd**	**iHg**	**Pb**	**Ni**
Cow milk[a]	0.0014	0.00051	0.00012	0.00043	0.00081
Milk replacer[b]					
Almond	0.00058	**0.0008**	**0.0018**	**0.0024**	**0.029**
Coconut	**0.0015**[d]	**0.0018**	**0.0018**	**0.0024**	**0.19**
Oat	0.0012	**0.0018**	**0.0018**	**0.0024**	**0.17**
Pea	**0.0040**	**0.0014**	**0.0018**	**0.0024**	**0.030**

Product	**Heavy metal concentration (mg/kg)**[c]				
ingredient	**iAs**	**Cd**	**iHg**	**Pb**	**Ni**
Rice	**0.016**	**0.0039**	**0.0018**	**0.0024**	**0.036**
Soy	0.00072	**0.0040**	**0.0018**	**0.0024**	**0.23**

[a] Analytical values for raw milk (cow (n=66) and goat (n=3)) were obtained from KAP (2019 to 2023).Heavy metals are predominantly analysed in raw milk and not in milk as consumed (whole milk, sem-skimmed milk or skimmed milk). Therefore, raw milk was taken as proxy.For Ni, only 30 measurements for raw milk were available.

[b] Analytical values for milk replacers were obtained from WFSR (analysed in 2024). The number of milk replacers analysed divided over the characteristic ingredients were 4, 5, 6, 2, 4 and 7 for almond, coconut, oat, pea, rice, and soy, respectively.

[c] Concentrations are shown for the middle bound scenario, which means that values below the level of quantification (LOQ) were assumed to be equal to half the value of the LOQ

[d] Concentrations in bold are higher compared to cow milk.

PFAS, dioxins and PCBs

PFAS concentrations were available or could be calculated for cow milk, milk drink and yoghurt replacers based on rice, pea and soy (Appendix 6). Concentrations were higher in cow milk (Table 4.6). For dioxins and PCBs, concentrations could be calculated for cheese and coconut oil-based cheese replacers and were highest in cheese (Table 4.6). This is consistent with the general observation that concentrations of PFAS, dioxins and PCBs are higher in foods of animal origin compared to foods of plant origin (EFSA 2012d, 2018c and 2020d). Therefore, these substances were not included for further prioritisation.

Table 4.6 Mean concentrations of PFAS, dioxins and dioxins-like poly chlorinated biphenyls (PCBs) and the sum of six indicator non-dioxin-like (NDL) PCBs in dairy products and dairy replacers

Food	**PFAS PEQ/kg product**[a]	**Dioxins and dioxin-like PCBs**[b] **(pg TEQ/ g product)**	**NDL-PCBs**[c] **(ng/g product)**
Cow milk	46	0.016	0.039
Milk (drink) and yoghurt replacers[d]			
Almond	NA[e]	NA	NA
Coconut	NA	NA	NA
Oat	NA	NA	NA
Rice	28	NA	NA
Pea	25	NA	NA
Soy	27	NA	NA
Cheese	46	0.16[f]	0.39[f]
Cheese replacers			
Almond	NA	NA	NA
Cashew	NA	NA	NA
Coconut oil	NA	0.0462	0.025

[a] Sum of 20 PFAS concentrations (expressed as PFOA equivalents PEQ, data obtained from Schepens et al., 2023). The middle bound scenario was estimated by averaging the lower bound and upper bound concentration (see Appendix 6).

[b] Sum of dioxins and dioxin-like polychlorated biphenyls (PCBs), expressed as Toxic Equivalents (TEQ) according to WHO (2005).

[c] Sum of 6 non-dioxin-like PCBs (PCB-101, PCB-138, PCB-153, PCB-180, PCB-28 and PCB-52)

[d] Calculated values using the standard recipes as described in Section 4.2 (same recipes used for milk (drink) and yoghurt replacers)and PFAS concentrations in foods (beans as a proxy for soy, pea and rice grains) and surface water (which had higher PFAS concentration than ground water.

[e] NA means not available or concentration could not be calculated due to lack of concentration data in certain ingredients.

[f] Calculated from cow milk, assuming 10 kg of milk is needed to produce 1 kg cheese.

AGEs

No Dutch concentration data were available for AGEs in dairy, but literature data were available (Table 4.7). Concentrations of CMEL, CEL and MGH in milk (drink) replacers were generally within the range observed in their dairy counterparts. Concentration data of AGEs in yoghurt replacers were not available. Because of similarity in the production process of milk drink and yoghurt replacers, concentrations in milk drinks replacers were used as proxy. Because comparable concentrations of AGEs were found in cow milk and in milk (drink) replacers, AGEs were not included for further prioritisation.

Table 4.7 Range of CML, CEL and MGH (mg/100 g) occurring in dairy and dairy replacers

Products	**CML**	**CEL**	**MGH**
Milk	0.01 – 0.26[a]	0.01 – 0.02[a]	0.02 – 0.30[a]
Milk drinks	0.04 – 1.01[a]	0.02 – 0.26[a]	0.12 – 0.98[a]
Milk (drink) and yoghurt replacer			
Almond	<0.02 – 0.03[b]	<0.01 – 0.02[b]	<0.02[b]
Coconut	<0.025[b]	<0.01 – 0.01[b]	<0.03 –0.01[b]
Oat	<0.01 – 0.05[b]	<0.01 – 0.04[b]	<0.01 – 0.1[b]
Pea	0.02 – 0.1[b]	<0.03[b]	NA[c]
Rice	<0.01[b]	<0.01[b]	<0.01[b]
Soy	<0.004 – 0.07[b]	<0.004 – <0.06[b]	<0.03[b]

CML: Nε–(carboxymethyl)lysine; CEL: Nε-(1-carboxyethyl)lysine; MGH: methylglyoxal hydroimidazolone

[a] Schijen et al. (2016)

[b] Indicative values from WFSR (2025)

c NA means not available

Comparison between meat replacers and meat products

Concentration data in meat replacers were available for the same substances as for dairy replacers, except for AGEs. PAHs are relevant for meat replacers (Table 4.2) and concentration data were available (Appendix 3). Substances for which no comparison could be made were addressed in the next prioritisation step.

Heavy metals

Compared with meat, concentrations of inorganic arsenic were higher in most meat replacers, except for soy- and pea-based slices (Table 4.8). Cadmium was also found in higher amounts in meat replacers, particularly in those intended for dinner and in wheat-based slices. Limited concentration data on inorganic mercury indicated higher concentrations in meat replacers for dinner than in meat. Lead was present in higher amounts in meat replacers for dinner and in pea-based slices. Nickel concentrations were higher in all meat replacers. Meat replacers with higher heavy metal concentrations than in their meat counterparts were included for further prioritisation. Since no iHg concentration data were available for Pâté replacers and slices, iHg in those products could not be taken into account for further prioritisation

Table 4.8 Middle bound concentrations of the heavy metals inorganic arsenic (iAs), cadmium (Cd), inorganic mercury (iHg), lead (Pb), and nickel (Ni) in meat and meat replacers

	Heavy metal concentration (mg/kg)[a]				
	iAs	**Cd**	**iHg[b]**	**Pb**	**Ni**
Meat[c]					
Chicken	0.0023	0.0026	0.0011	0.0036	0.0080
Beef	0.0023	0.0026	NA	0.0036	0.0080
Pork	0.0023	0.0027	0.0012	0.0037	0.0086
Meat replacer dinner[d]					
Soy	**0.0054[f]**	**0.020**	**0.0025**	**0.013**	**0.77**
Wheat	**0.0072**	**0.015**	**0.0025**	**0.011**	**0.28**
Pea	**0.0050**	**0.014**	**0.0025**	**0.010**	**0.32**
Pâté replacer[e]					
Soy	**0.0031**	0.0018	NA	0.0020	**0.214**
Wheat	**0.0042**	**0.0032**	NA	0.0021	**0.021**
Pea	**0.0031**	0.0016	NA	0.0030	**0.172**
Slices[e]					
Soy	0.0005	**0.0037**	NA	0.0024	**0.609**
Wheat	**0.0037**	**0.0079**	NA	0.0026	**0.056**
Pea	0.0005	**0.0033**	NA	**0.0050**	**0.488**

NA not available

[a] Concentrations are middle bound estimates, which means that values below the level of quantification (LOQ) were assumed to be equal to half the value of the LOQ.

[b] Concentration data only available for meat and meat replacers for dinner.

[c] Analytical data obtained from the KAP database (2019 – 2023; n=40, 27 and 85 for chicken, beef and pork, respectively).

[d] Analytical data obtained from WFSR (2025). The number of meat replacers for dinner were 21, 8 and 8 for soy, wheat and pea, respectively.

[e] Heavy metal concentrations in pâté replacers and slices were calculated using main recipes (Section 4.2) and concentrations of heavy metals in ingredients which were obtained from KAP.

[f] Concentrations in bold indicate higher concentrations in replacers compared with meat.

PFAS, dioxins and PCBs

For PFAS, dioxins and PCBs, concentration data in meat and meat replacers were available. For all these substance groups the concentrations were generally higher in meat products than in meat replacers (Table 4.9). Only the concentrations of dioxins and dioxin-like PCBs in pâté replacers were comparable to pâté. Therefore, PFAS, dioxins and PCBs were not included for further prioritisation.

Table 4.9 Mean concentrations of PFAS, dioxins and dioxins-like polychlorinated biphenyls (PCBs) and the sum of six indicator non-dioxin-like (NDL) PCBs in dairy products and dairy replacers

Food	**PFAS PEQ/kg product[a]**	**Dioxins and dioxin-like PCBs[b] (pg TEQ/g product)**	**Sum 6 indicator NDL-PCBs[c] (ng/g product)**
Meat	97-115[d]	0.012-0.14[g]	0.036-0.44
Meat replacers for dinner	26-30[e]	0.0046[h]	0.016[h]
Pâté	143-149[f]	0.028i	0.101[i]
Pâté replacers	29-31[e]	0.029[j]	0.034[j]
Slices	NA	0.026[k]	0.101[k]
Slices replacers	42-47[e]	0.014[l]	0.045[l]

[a] Sum of 20 PFAS concentrations (expressed as PFOA equivalents PEQ, data obtained from Schepens et al., 2023). The middle bound scenario was estimated by averaging the lower bound and upper bound concentration (see Appendix 6).

[b] Sum of dioxins and dioxin-like polychlorinated biphenyls (PCBs), expressed as Toxic Equivalents (TEQ) according to WHO (2005).

[c] Sum of the 6 non-dioxin-like PCBs (PCB-101, PCB-138, PCB-153, PCB-180, PCB-28 and PCB-52).

[d] Range of PFAS reported for meat (beef, pork and minced meat).

[e] Calculated values for pea, soy and wheat-based replacers using the standard recipes as described in Table 4.1 Section 4.2 and PFAS concentrations in foods (beans as a proxy for soy, pea, wheat flour, eggs, sunflower oil and olive oil) and groundwater (which had a higher PFAS concentration than surface water).

[f] Range of PFAS reported for pâté and pork liver sausages.

[g] Range of concentration TEQ in meat (veal, beef, chicken, pork and mutton, calculated from the analysed concentrations in fat and assuming a mean fat concentrations in meat products of these species of 13.3%.

[h] Calculated value using the standard recipe described in in Table 4.1 Section 4.2 and a dioxin and dioxine-like PCB concentration of 0.066 pg TEQ /g a NDL-PCB concentration of 0.223 ng/g for sunflower oil, the most frequently used vegetable in meat replacers for dinner according to the branded food label database LEDA.

[i] Calculated value assuming a fat content of 29% pork fat (the fat concentration of spreadable pork liver sausage according to the Dutch Nutrition Database NEVO. Spreadable pork liver sausage is the most frequently consumed liver sausage according to the DNFCS).

[j] Calculated value using the standard recipe described in Table 4.1 Section 4.2 and a dioxin and dioxine-like PCB concentration of 0.066 pg TEQ /g for sunflower oil and 0.22 pg TEQ /g for coconut oil, respectively. Sunflower oil and coconut oil are the two most frequently used vegetable oils in pâté replacers and were assumed to be equally present. For NDL-PCBs, the concentrations used were 0.12 and 0.22 ng/g product for coconut oil and sunflower oil, respectively.

[k] Similar as for pâté, but with assuming a fat content of 27% (the fat concentration of luncheon meat according to NEVO. Luncheon meat is a frequently consumed product according to NEVO).

[l] Similar as for pâté replacers. It should be noted that dioxin and PCB concentrations were not available for soy oil, thus the concentration of those substances is slightly underestimated.

PAHs

Ideally, PAHs concentration data in frequently consumed meat products on the Dutch market prepared according to the most frequently used home cooking methods are used to make the comparison between meat and meat replacers. However, no recent Dutch PAH4 concentrations in meat were available, PAH4 concentrations in meat replacers from 2020 were compared with concentrations in meat obtained from EFSA (2008). Concentrations in meat replacers were comparable to those reported by EFSA, and higher than in grilled meat, smoked meat, other types of meat or meat unspecified (Table 4.10). In controlled studies using the same method of heat-treatment for both meat and meat replacers, lower amounts of PAH4 were observed in wheat-based meat replacers (Zastrow et al., 2022) and tofu (as a proxy of soy-based meat replacers, Wu et al., 2025). Since no definite conclusion can be made based on the comparison between meat and replacers, PAHs were considered for further prioritisation.

Table 4.10 Overview of the sum of four poly aromatic hydrocarbons (PAH4) occurring in meat products and meat replacers

	PAH4 (µg/kg)	**Source**
Meat	1.4^{a}	EFSA (2008)
Barbequed meat	5.2^{a}	EFSA (2008)
Grilled meat	2.^{3a}	EFSA (2008)
Smoked meat	1.9^{a}	EFSA (2008)
Other	0.4^{a}	EFSA (2008)
Meat replacer	5.3^{b}	KAP data

[a] EFSA did not present middle bound concentration values (values below the limit of quantification (LOQ) were assumed to equal half the value of the LOQ values) but only lower bound values (values below the LOQ were assumed to equal zero) and upper bound values (values below the LOQ were assumed to equal the value of the LOQ). The mean of the lower bound and upper bound values was therefore used as a proxy of the middle bound concentration value.

[b] Middle bound concentration value.

4.4.3 *Conclusion*

In conclusion, the following substances remained after the third step of the prioritisation process:

Heavy metals (based on comparison with dairy and meat)

- Inorganic arsenic (meat replacers, except soy and pea-based slices)
- Cadmium replacers for dinner meat, wheat-based slices)
- Lead (meat replacers for dinner meat, pea-based slices)
- Inorganic mercury (dairy replacers, meat replacers for dinner meat)
- Nickel (milk drink and yoghurt replacers based on coconut, oat, rice and soy, meat replacers)

Mycotoxins (no comparison with dairy and meat possible)

- *Alternaria* toxins (AOH, AME, TEN en TeA)
- Aflatoxin (AFB$_1$, AFB$_2$, AFG$_1$and AFG$_2$)
- DON and metabolites
- Enniatins (A, A1, B, B1)

- Ergot alkaloids
- Fumonisins (FB_1, FB_2, FB_3 and FB_4)
- OTA
- T-2 and HT-2 toxins
- ZEA and metabolites

Plant toxins (no comparison with dairy and meat possible)
- Cyanogenic glycosides (only dairy replacers)
- Erucic acid (only meat replacers)
- Tropane alkaloids

Others (no comparison with dairy and meat possible)
- Nitrate
- MOSH (only meat replacers)
- MOAH (only meat replacers)
- Perchlorate

Processing contaminants (no comparison with dairy and meat possible)
- Acrylamide
- GEs
- 3-MCPD
- PAHs

A full overview of included substances per type of replacer and characteristic ingredient is given in Appendix 1.

4.5 Step 4: Ranking based on exposure grades

The comparison of concentrations of substances in replacers and in dairy and meat did not lead to a substantial elimination of substances. In the next prioritisation step, both the current (baseline) exposure to the remaining 25 substances/substance groups and the expected additional exposure via dairy and meat replacers was considered. The exposure was expressed as a percentage of the toxicological reference value (TRV). To prioritize the substances, a grading was subsequently assigned to the obtained percentage. This grading is called exposure grades in this report.

The rationale behind this approach is that ranking based on exposure grades takes into account the mean and P95 baseline exposure, and the additional exposure via consumption of replacers (mean and P95). For example, if both mean and P95 baseline exposure are already high, and both mean and P95 additional exposure are high, the substance will be given higher priority than when only P95 baseline exposure and P95 additional exposure are high, since a larger part of the population will be affected.

The methodology used for the ranking based on exposure grades is described in Section 4.5.1 and the results in Section 4.5.2. Ranking based on exposure grades was performed for all substances indicated in Section 4.4.3 and for which a TRV is available.

4.5.1 *Methodology ranking based on exposure grades*

The mean and high (P95) consumptions of dairy and meat replacers, in Tables 2.1 and 2.2 were used for assigning exposure grades. First, the exposure to the substances via the standard portions of replacers was calculated. Next, the baseline exposure to these substances via other foods and drinking water was also taken into account. To facilitate the ranking, an exposure grade was assigned to the (calculated) mean and P95 exposures. The ranking steps are explained in more detail below.

Exposure via standard portions of dairy and meat replacers
For each substance and each type of replacer, the standard portions were multiplied with the average concentration of the substance in the dairy or meat replacer and divided by a standard body weight of 14 kg for children from 1- to 3-years-old and 81 kg for adults (mean body weight of these age groups according to the DNFCS). This resulted in a rough estimate of the expected additional chronic exposure to the substance via the consumption of dairy and meat replacers. Exposures for each substance, replacer, portion size (mean and P95) and population are provided in Appendix 7 for dairy replacers and in Appendix 8 for meat replacers.

Baseline exposure
For the baseline chronic exposure, the most recent exposure estimates for the Dutch population published by RIVM or, if not available, by EFSA for children aged 1 – 3 years and adults was used. Sometimes, there was not a perfect match between available age groups in those assessments and the ones in our study. In that case, the age group with the best match was selected. For example, for mycotoxins, data from a Dutch total diet study was available for persons aged 6-69 years, which was used as an estimate of the exposure for adults. If possible, the middle bound (MB) exposure was used. If such exposure was not provided, the average value of the lower and upper bound estimates was used as proxy. Sometimes mean exposures were not available and P50 values were used instead. Appendix 9 shows the baseline exposures used in this report.

Toxicological reference values
The calculated exposure to substances due to consumption of dairy and meat replacers was then expressed as percentage of their respective chronic TRVs. The same was done for the baseline exposure. An overview of the chronic TRVs used for this can be found in Table 4.11. For enniatins, no TRV was available and, therefore, this substance could not be included in the ranking of exposure grades. As indicated in Section 2.1, the focus in this project was on chronic exposure. Tropane alkaloids exert acute effects (EFSA, 2013), therefore, these substances were excluded. Cyanogenic glycosides exerts both acute and chronic effects and only the chronic effect was included.

Table 4.11 Overview of the toxicological reference values (TRVs)

Substance	**TRV**	**Type TRV**	**Reference**
Heavy metals			
iAs	0.06 µg/kg bw per day	$BMDL_{05}$ / MOE of 1	EFSA (2024)
iHg	0.57 µg/kg bw per day	TWI / 7	EFSA (2012a)
Cd	0.36 µg/kg bw per day	TWI / 7	EFSA (2009)
Pb	Children: 0.05 µg/kg bw per day Adults: 0.063 µg/kg bw per day	$BMDL_{01}$ / 10	EFSA (2010b)
Ni	13 µg/kg bw per day	TDI	EFSA (2020c)
Mycotoxins			
AOH, AME	2.5 ng/kg bw per day	TTC	EFSA (2011)
Aflatoxins (sum)	0.00004 µg/kg bw per day	$BMDL_{10}$ / MOE of 10.000	EFSA (2020a)
DON and metabolites	1 µg/kg bw per day	TDI	EFSA (2017a)
Ergot alkaloids	0.6 µg/kg bw per day	TDI	EFSA (2012)
Fumonisins (sum)	1 µg/kg bw per day	TDI	EFSA (2018a)
TEN/TeA	1,500 ng/kg bw per da	TTC	EFSA (2011)
T-2 and HT-2 toxin (sum)	0.02 µg/kg bw per day	TDI	EFSA (2017b)
OTA	0.02365 µg/kg bw per day	$BMDL_{10}$ / MOE of 200	EFSA (2020b)
ZEA	0.25 µg/kg bw per day	TDI	EFSA (2016b)
Plant toxins			
Cyanogenic glycosides	20 µg/kg bw per day	PMTDI	JECFA (2011)
Erucic acid	7000 µg/kg bw per day	TDI	EFSA (2016d)
Process contaminants			
Acrylamide	0.0017 µg/kg bw per day	$BMDL_{10}$ / MOE of 10.000	EFSA (2015a)
3-MCPD	2 µg/kg bw per day	TDI	EFSA (2018b)
GEs	0.408 µg/kg bw per day	T_{25} / MOE of 25.000	EFSA (2016e)
PAH4	0.023 µg/kg bw/day	$BMDL_{10}$ / MOE of 10.000	EFSA (2008)
Other			
MOSH	200 µg/kg bw per day	NOAEL / MOE of 1200	EFSA (2023)
MOAH	0.05 µg/kg bw per day	$BMDL_{10}$ / MOE of 10.000	EFSA (2023)
Nitrate	3.7 mg nitrate ion/kg bw/day	ADI	EFSA (2017c)

Substance	**TRV**	**Type TRV**	**Reference**
Perchlorate	1.4 ug/kg bw/day	TDI	EFSA (2025c)

Abbreviations substances: Abbreviations substances: AOH: alternariol; AME: alternariol methyl ether; Cd: cadmium; deoxynivalenol (DON) and metabolites (3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside); GEs: glycidyl esters; iAs: inorganic arsenic; iHg: inorganic arsenic; 3-MCPD: 3-monochloropropane-1,2-diol; MOSH: mineral oil saturated hydrocarbons; MOAH: mineral oil aromatic hydrocarbons; Ni: Nickel; OTA: ochratoxin; PAH4: sum of 4 poly aromatic hydrocarbons; Pb: lead; TeA: Tenuazonic acid; TEN: tentoxin; ZEA: Zearalenone.
Abbreviations health-based guidance values: ADI: acceptable daily intake; BMDL: bench mark dose lower limit; MOE: margin of Exposure; NOAEL: no observed adverse effect level; PMTDI: provisional maximum tolerable daily intake; T_{25}: the chronic daily dose in mg per kg bodyweight which will give 25% of the animals tumours at a specific tissue site, after correction for spontaneous incidence, within the standard life span of that species; TDI: tolerable daily intake; TWI: tolerable weekly intake.

Exposure grades

A grade was given to the exposures based on the following criteria:

- exposure <10% of TRV – grade 1;
- 10% of TRV ≤ exposure <100% of TRV – grade 3;
- exposure ≥ 100% TRV – grade 5.

This was done for each type of replacer (dairy: replacers of milk, yoghurt and cheese; meat: replacers of dinner meat, paté and slices), each characteristic ingredient, age group (1- to 3-year-olds and adults) and portion size (standard mean or standard P95 portion), respectively. The baseline exposure to these substances, also at the mean and P95, was graded in the same way.

Ranking based on exposure grades

The obtained exposure grades for the mean and high (P95) consumption of each type of replacer were summed and added to the sum of the exposure grades for the mean and high (P95) baseline exposure. For example, the exposure grades obtained for the mean and P95 dietary exposure to cadmium in soy-based milk (drink) replacers were summed for adults. In addition, the exposure grades for the mean and P95 of the baseline exposure to cadmium were summed for the adults. Finally, the summed cadmium exposure grade via the soy-based milk drink replacer for adults was summed with the summed cadmium exposure grade for the baseline cadmium exposure for this age group, resulting in the total exposure grade. This was done for all substances, all types of replacers and for both age groups.

Box 3 provides an example on how exposure grades were obtained.

Box 3 Example of summing exposure grades: dietary cadmium exposure in adults.

Appendix 9 shows that the most recent mean dietary exposure estimate for cadmium in the adult populations was 0.26 µg/kg bw per day. If this was divided by the TRV for cadmium of 0.36 µg/kg bw per day (Table 4.11), then the exposure filled 72% of this TRV. According to the arbitrary rules explained in Section 4.5.1, this resulted in an exposure grade of 3.
If this was done for the P95 exposure of 0.48 µg/kg bw per day, 133% of the TRV was filled and an exposure grade of 5 was assigned. To subsequently obtain the exposure grade for the baseline exposure, the exposure grade for the mean and P95 was summed: 3+5=8.

The cadmium exposure via consumption of a mean standard portion of soy-based milk-drink replacer in adults (314 g, Table 2.1) was 0.016 µg/kg bw per day, which was 4.3% of the TRV and thus was assigned an exposure grade of 1. The P95 consumption of soy-based milk-drink replacers in adults (773 g) resulted in an exposure of 0.038 µg/kg bw per day, which was 10.6% of the TRV and thus an exposure grade of 3 was assigned. Summing the mean and P95 exposure grade for cadmium via milk drink replacers yielded a summed exposure grade of 1+3=4.

The total exposure grade was obtained by summing the exposure grade for the baseline (8) and the exposure grade for the consumption of soy-based milk (drink) replacers (4), i.e. 8+4=12. This total exposure grade was used for risk ranking in adults.

The advantage of summing exposure grades in this way is that it takes into account both the mean and P95 consumption of the baseline exposure as well as the additional exposure due to consumption of dairy and meat replacers.

4.5.2 *Results prioritisation*

Baseline exposure

Baseline exposures and their gradings are presented in Appendix 9. Table 4.12 summarizes the exposure grades. The highest summed exposure grades in 1- to 3-year-olds were obtained for cadmium, lead, inorganic arsenic, inorganic mercury, MOAH, AOH, AME, aflatoxins, acrylamide and GEs, all equal to 10. This means that for these substances both the mean and P95 baseline exposure already exceeded the respective TRVs. Any additional exposure to a substance due to the consumption of dairy and meat replacers may further increase this concern. The lowest total baseline exposure grade was obtained for TEN (exposure grade 2).

Regarding adults, the exposure grades of inorganic arsenic, lead, MOAH, AOH, AME, aflatoxins and acrylamide equaled 10, indicating that the respective TRVs were already exceeded, and the lowest exposure grade was for ZEA and TEN (exposure grade 2).

Table 4.12 Exposure grades for the mean, 95th percentile (P95) and the sum of these exposure grades for the baseline exposure of Dutch 1- to 3-year-olds and adults to substances potentially present in dairy and meat replacers

Substance	**Exposure grade baseline**					
	1-3 years			**Adults**		
	Mean	**P95**	**Sum**	**Mean**	**P95**	**Sum**
Metals						
Cd	5	5	10	3	5	8
iAs	5	5	10	5	5	10
iHg	5	5	10	3	3	6
Ni	3	3	6	3	3	6
Pb	5	5	10	5	5	10
Mycotoxins						
AOH	5	5	10	5	5	10
AME	5	5	10	5	5	10
Aflatoxins	5	5	10	5	5	10
DON and metabolites	3	3	6	3	3	6
Fumonisins	1	3	4	3	3	6
OTA	3	3	6	3	3	6
TEN	1	1	2	1	1	2
TeA	3	3	6	1	3	4
T-2 and HT-2 toxins	3	5	8	3	5	8
ZEA	1	3	4	1	1	2

Substance	Exposure grade baseline					
	1-3 years			Adults		
	Mean	P95	Sum	Mean	P95	Sum
Plant toxins						
Cyanogenic glycosides	3	5	8	1	3	4
Erucic acid	3	3	6	3	3	6
Process contaminants						
3-MCPD	3	5	8	3	5	8
Acrylamide	5	5	10	5	5	10
GEs	5	5	10	3	5	8
PAH4	3	5	8	3	3	6
Others						
Nitrate	3	5	8	3	3	6
Perchlorate	3	3	6	1	3	4
MOAH	5	5	10	5	5	10
MOSH	5	3	8	3	3	6

Abbreviations substances: AOH: alternariol; AME: alternariol methyl ether; Cd: cadmium; deoxynivalenol (DON) and metabolites (3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside)l; GEs: glycidyl esters; iAs: inorganic arsenic; iHg: inorganic arsenic; 3-MCPD: 3-monochloropropane-1,2-diol; MOSH: mineral oil saturated hydrocarbons; MOAH: mineral oil aromatic hydrocarbons; Ni: Nickel; OTA: ochratoxin; PAH4: sum of 4 poly aromatic hydrocarbons; Pb: lead; TeA: tenuazonic acid; TEN: tentoxin; ZEA: zearalenone.
[a] The most recent Dutch exposure assessments were used to generate exposure grades. Appendix 9 lists the mean and 95th percentile exposures used for deriving exposure grades. Exposure grade 1 was assigned if the background exposure was less than 10% of the health-based guidance value (HBGV), exposure grade 3 was assigned if the exposure was between 10 and 100% of the HBGV, and finally an exposure grade 5 was given if the exposure was 100% or more of the HBGV.

Ranking total exposure grades substances dairy replacers

Appendix 7 shows a full overview of the exposure grades (sum of mean and P95) via consumption of dairy replacers. It also shows the total exposure grades (sum of baseline exposure grades and via consumption of dairy replacers) per substance/dairy replacer combination and for each age group, as well as the ranking of the total exposure grades for milk (drink) replacers, yoghurt replacers and cheese replacers, respectively and across dairy replacers.

Table 4.13 and 4.14 show the top three highest total exposure grades across all dairy replacers for 1- to 3-year-olds and adults, including the baseline exposure grades, respectively. The top three total highest exposure grades were observed for inorganic arsenic, cadmium (1- to 3-year-olds), lead, aflatoxins, AOH, AME, acrylamide, T-2 and HT-2 toxins, and DON and metabolites (1- to 3-year-olds).

Table 4.13 The top 3 highest total exposure grades for substances in dairy replacers in 1- to 3-year-olds[a]

Substance	**Type replacer**	**Characteristic ingredient**
Exposure grade 20		
Aflatoxins	Milk drink	Almond
		Oat
		Rice
	Yoghurt	Almond
		Oat
	Cheese	Almond
		Cashew
AOH	Milk drink	Almond
		Oat
		Rice
		Soy
	Yoghurt	Almond
		Oat
		Soy
	Cheese	Almond
		Cashew
AME	Milk drink	Almond
		Oat
		Rice
		Soy
	Yoghurt	Almond
		Oat
		Soy
	Cheese	Almond
		Cashew
Acrylamide	Milk drink	Almond
		Coconut
		Oat
		Pea
		Rice
		Soy
	Yoghurt	Almond
		Coconut
		Oat
		Soy
iAs	Milk drink	Pea
		Rice
Pb	Milk drink	Almond
		Coconut
		Oat
		Pea
		Rice
		Soy
Exposure grade 18		
T-2 and HT-2 toxins	Milk drink	Oat
	Yoghurt	Oat
iAs	Milk drink	Coconut

Substance	**Type replacer**	**Characteristic ingredient**
Exposure grade 16		
T-2 and HT-2	Cheese	Almond
		Cashew
		Coconut
DON and metabolites	Milk drink	Oat
iAS	Cheese	Almond
	Yoghurt	Coconut
Cd	Milk drink	Oat
		Rice
		Soy
	Yoghurt	Soy
Pb	Yoghurt	Almond
		Coconut
		Oat
		Soy

Abbreviations substances: AOH: alternariol; AME: alternariol methyl ether; Cd: cadmium; DON: deoxynivalenol, and metabolites (3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside); iAs: inorganic arsenic; Pb: lead.

[a] total exposure grades included the exposure grades assigned to the mean and P95 dietary exposure via replacers and to the mean and P95 baseline dietary exposure.

Table 4.14 The top 3 highest total exposure grades for substances in dairy replacers in adults[a]

Substance	**Type replacer**	**Characteristic ingredient**
Total exposure grade 20		
Aflatoxins	Milk drink	Almond
		Oat
		Rice
	Yoghurt	Almond
		Oat
	Cheese	Almond
		Cashew
AOH	Milk drink	Almond
		Oat
		Rice
		Soy
	Yoghurt	Almond
		Oat
		Soy
	Cheese	Almond
		Cashew
AME	Milk drink	Almond
		Oat
		Rice
		Soy
	Yoghurt	Almond
		Oat
		Soy
	Cheese	Almond
		Cashew
Acrylamide	Milk drink	Almond

Substance	**Type replacer**	**Characteristic ingredient**
		Coconut
		Oat
		Pea
		Rice
		Soy
		Wheat
	Yoghurt	Almond
		Coconut
		Oat
		Soy
iAs	Milk drink	Rice
Total exposure grade 18		
T-2 and HT-2 toxins	Milk drink	Oat
	Yoghurt	Oat
Total exposure grade 16		
iAs	Milk drink	Pea
Pb	Milk drink	Almond
		Coconut
		Oat
		Pea
		Rice
		Soy
	Yoghurt	Almond
		Coconut
		Oat
		Soy

Abbreviations substances: AOH: alternariol; AME: alternariol methyl ether; Cd: cadmium; iAs: inorganic arsenic; Pb: lead.

[a] total exposure grades included the exposure grades assigned to the mean and P95 dietary exposure via replacers and to the mean and P95 baseline dietary exposure.

Ranking total exposure grades substances in meat replacers
Appendix 8 shows a full overview of the total exposure grades per substance/meat replacer combination and for each age group. The top three highest total exposure grades across all meat replacers for 1- to 3-year-olds and adults are shown in Tables 4.15 and 4.16, respectively. Aflatoxins, AOH, AME, acrylamide, MOAH, lead, inorganic arsenic and erucic acid were amongst the top three highest exposure grades in both age groups. Cadmium, PAHs and GEs were also amongst the top three highest exposure grades in 1- to 3-year-olds.

Table 4.15 The top 3 highest total exposure grades for substances in meat replacers in 1- to 3-year-olds[a]

Substance	**Type replacer**	**Characteristic ingredient**
Total exposure grade 20		
Aflatoxins	Dinner meat	Unspecified
	Pâté	Wheat
	Slices	Wheat
AOH	Dinner meat	Wheat
	Slices	Pea
		Soy
		Wheat
AME	Dinner meat	Wheat
	Pâté	Pea
		Soy
		Wheat
	Slices	Pea
		Soy
		Wheat
Acrylamide	Dinner meat	Unspecified
MOAH	Dinner meat	Unspecified
	Pâté	Unspecified
	Slices	Unspecified
Total exposure grade 18		
AOH	Pâté	Pea
		Soy
		Wheat
Pb	Dinner meat	Pea
		Soy
		Wheat
Total exposure grade 16		
Cd	Dinner meat	Pea
		Soy
		Wheat
iAs	Dinner meat	Pea
		Soy
		Wheat
	Pâté	Wheat
Pb	Slices	Pea
Erucic acid	Dinner meat	Unspecified
	Pâté	Unspecified
PAH4	Dinner meat	Unspecified
GEs	Dinner meat	Pea
		Soy
		Wheat
	Pâté	Unspecified
	Slices	Unspecified

Abbreviations substances: AOH: alternariol; AME: alternariol methyl ether; Cd: cadmium; GEs: glycidyl esters; iAs: inorganic arsenic; MOAH: mineral oil aromatic hydrocarbons; PAH4: sum of 4 poly aromatic hydrocarbons; Pb: lead.

[a] Total exposure grades included the exposure grades assigned to the mean and P95 dietary exposure via replacers and to the mean and P95 baseline dietary exposure.

Table 4.16 The top 3 highest total exposure grades for substances in meat replacers in adults[a]

Substance	Type replacer	Characeristic ingredient
Exposure grade 20		
Aflatoxins	Dinner meat	Unspecified
	Pâté	Wheat
	Slices	Wheat
AME	Dinner meat	Wheat
	slices	Pea
		Soy
		Wheat
Acrylamide	Dinner meat	Unspecified
MOAH	Dinner meat	Unspecified
	Pâté	Unspecified
	Slices	Unspecified
Exposure grade 18		
AOH	Dinner meat	Wheat
AME	Pâté	Pea
		Soy
		Wheat
Exposure grade 16		
AOH	Pâté	Pea
		Soy
		Wheat
	Slices	Pea
		Soy
		Wheat
Pb	Dinner meat	Pea
		Soy
		Wheat
iAs	Dinner meat	Pea
		Soy
		Wheat
Erucic acid	Pâté	Unspecified

Abbreviations substances: AOH: alternariol; AME: alternariol methyl ether; Cd: cadmium; iAs: inorganic arsenic; MOAH: mineral oil aromatic hydrocarbons; Pb: lead.

[a] total exposure grades included the exposure grades assigned to the mean and P95 dietary exposure via replacers and to the $^{\text{mean}}$ and P95 baseline dietary exposure.

4.6 Step 5: Expert judgement of available concentration data

The next step in the process for prioritising is an expert judgement of the available concentration data for the substances selected in the previous step (Section 4.5.2). This is important since these data are to be used in the dietary exposure assessment using substitution scenarios (see Chapter 5). In the prioritisation process, mean concentrations of substances according to the MB scenario were used. This means that values below the LOQ were assumed to equal half the value of the LOQ, and thereby that those mean concentrations can be affected by the value of the LOQ if insensitive analytical methods with high LOQs were used. Such concentration data are less suitable for performing dietary exposure assessments, because MB substitution of high LOQ values would result in an overestimation of the dietary exposure. This section gives a summary of the expert judgment for the suitability of the concentration data. A detailed overview is given in Appendix 10.

Concentration data of the identified mycotoxins (AOH, AME, aflatoxins, T-2 and HT-2 toxins and DON and metabolites) in dairy and meat replacers were obtained using a multi method. Such an analytical method analyses multiple mycotoxins within a single run, and is highly valuable for enforcement purposes. The LOQ is set in such a way to detect whether the concentrations of mycotoxins remain below regulatory maximum levels. However, this method is less suitable for risk assessment purposes due to these relatively high LOQ values (varying from 0.05 µg/kg for aflatoxins to 100 µg/kg for AOH and AME in milk (drink) replacers). Indeed, all mycotoxin concentrations obtained with this method were below the LOQ. In literature, results obtained from more sensitive analytical methods with LOQs varying from 0.001 µg/kg for aflatoxins to 11 µg/L for DON and metabolites in milk (drink) replacers showed that AOH, AME, aflatoxins, T-2 and HT-2 toxins, and DON and metabolites can occur in quantifiable amounts. Therefore, concentration data of mycotoxins obtained from the insensitive multimethod were not considered for a dietary exposure assessment. Before an exposure assessment and subsequently a risk assessment is conducted, these mycotoxins should be measured using a sensitive analytical method.

In our study, calculated values of erucic acid were used for the prioritisation, with only 7% of analysed values for edible oils above the LOQ. As a consequence, these concentration data are not suitable for dietary exposure assessment. Concentration data for erucic acid in rapeseed-containing meat replacers measured with a sensitive method are needed for this.

No concentration data were available for PAHs in dairy replacers based on (roasted) almond and oat. Further, even though concentration data were available in meat replacers, this was only the case for PAH4. EFSA (2008) derived also a $BMDL_{10}$ covering eight PAHs (benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, chrysene, dibenz[a,h] anthracene and indeno[1,2,3-cd]pyrene). To assess the possible health risk of exposure to PAHs, it is therefore preferable to include all eight PAHs.

The concentration data available for acrylamide, MOAH, GEs, inorganic arsenic, cadmium and lead in dairy and meat replacers were considered suitable for dietary exposure assessment.

4.7 Step 6: Availability of recent Dutch dietary exposure assessments

In the next step, the availability of recent Dutch dietary exposure assessments is investigated. A dietary exposure assessment using substitution scenarios for dairy and meat with replacers to investigate if a shift towards a diet with more plant-based replacers will result in an increased exposure to the prioritised substances, is a laborious task. This is mainly due to linking the consumed foods to the analysed foods. Therefore, given the budget restriction for this project, dietary exposure assessments for substitution scenarios could only be performed when a recent baseline assessment was already available (and thereby the links between consumed and analysed foods). Since dietary habits may change over time, an additional prerequisite was that these dietary exposure assessments were based on food consumption data of the most recent DNFCS (2019-2021).

The latest exposure assessments for inorganic arsenic, acrylamide, MOAH and GEs were performed using food consumption data of older DNFCSs (Appendix 9). For inorganic arsenic and acrylamide, dietary exposure assessments will become available in 2026 as part of a project commissioned by the Ministry of Health, Welfare and Sports which aims to study the impact of chemicals on common diseases (CoVo project).. Therefore, the dietary exposure assessment for these substances could not be performed in the current project. For cadmium and lead, the same KAP dataset was used as for a project financed by the Ministry of Health, Welfare and Sports investigating the effect on dietary exposure to chemicals when the new dietary guidelines of Health Council are followed (Wheal of five project). This dataset was used for the baseline exposure assessment in the current project, including substitution scenarios for dairy and meat (Chapter 5).

4.8 Discussion

The implications of the scope of the study are discussed in Section 4.8.1, the advantages and limitations of the prioritisation procedure in Section 4.8.2 and the uncertainties affecting the outcome of the prioritisation Section 4.8.3.

4.8.1 Scope of the study

The focus of the current study was the prioritisation of substances present in industrially produced replacers. In reality, it cannot be excluded that consumers who want to consume less or no dairy and meat may make other changes in their dietary pattern, like eating more nuts and beans instead of industrially-produced replacers. Such information was not available from the DNFCS 2019-2021 because the amount of plant-based food consumers was low and consumers were not questioned about their intentions. Therefore, these changes in dietary pattern could not be taken into account. Changes in dietary pattern other than the consumption of industrially-produced replacers may lead to other priority substances.

The prioritisation process included a ranking based on total exposure grades, which were obtained by expressing baseline dietary exposure and additional exposure via dairy and meat replacers as a percentage of the TRV. Substances without a TRV (e.g. enniatins, AGEs) could therefore not be taken into account, while it can be assumed that the exposure to (part of) these substances will be increased when consuming more plant-based products.

The current project focussed on chronic effects. Some of the substances also exert acute effects, like cyanogenic glycosides and tropane alkaloids. For these substances, point estimates as a first tier for acute exposure and risk assessment could be performed by using the highest quantifiable concentrations in replacers and calculating the amount of replacer to be consumed until the acute reference dose is reached. However, this was beyond the scope of the current project.

4.8.2 *Advantages and limitations of the process for prioritisation*

A major advantage of the step-wise approach described in this report is that the prioritisation is risk-driven, i.e. it takes into account the exposure to a substance via the replacer and its baseline exposure. This helps to focus on those substances that may have an elevated dietary exposure and hence a possible increased risk due to increased consumption of dairy replacers and meat replacers. Many publications in literature only describe the hazard of substances in dairy and meat replacers (Banach et al., 2022) or provide a risk ranking for the exposure via the replacers and do not take into account the baseline exposure (Schrijver et al., 2025).

A limitation of the process for prioritisation is the limited availability of concentration data of products on the Dutch market. Country-specific variations in recipes of dairy and meat replacers, the preferred method of home preparation (for meat replacers for dinner) and contamination of substances in crops (e.g. heavy metals) may occur. Therefore, concentration data from other countries may not be relevant for the Netherlands and the use of Dutch concentration data is preferred for dietary exposure assessments.

For isoflavones, AGEs (in case of meat replacers for dinner), protease inhibitors and lectins , no Dutch concentration data were available. Other studies showed that isoflavones are likely present in soy-based dairy and meat replacers (ANSES, 2011; USDA, 2015; Lee et al., 2022) and in a French study it was concluded that the exposure to isoflavones in children may be a concern (ANSES, 2025). The Health Council of the Netherlands noted in 2025 that ANSES derived a TRV of 0.01 mg/kg (based on decreased relative weight of the epididymis in male rats and decreased litter size) and that evidence from human studies was not taken into account. Effects of isoflavones in rats may not be representative for effects in humans because of metabolic differences between species (Health Council, 2025b). The Health Council also noted that the evidence on the potential adverse effects of isoflavones should be weighed against the evidence on favourable health effects of soy. They concluded that at present, the knowledge is insufficient to draw a clear conclusion on isoflavones and soy.

Also AGEs in meat replacers may occur, but concentrations seemed comparable to those in heated meat (Schijen et al., 2016). Therefore, dietary exposure to AGEs in meat replacers may not be (largely) increased if meat is substituted by replacers.

Regarding lectins and protease inhibitors, heat treatment will destroy their biological activity. Hence, concentration data of industrially produced and, in case for meat replacers for dinner, of home-prepared replacers are needed to judge if lectins and protease inhibitors are still biologically active. An EFSA opinion on lectins is to be expected soon (EFSA, 2025d). No lectin concentrations were available from the EFSA data warehouse. EFSA used literature data instead. The Panel also noted that exposure to completely deactivated lectins in food prepared following adequate food processing practices (e.g. soaking and boiling) would not raise health concerns. Also the Health Council of the Netherlands concluded that lectins are destroyed when dried legumes are soaked for at least 12 hours and then boiled for at least 10 minutes. Tinned legumes have already undergone this process applied and so can be used without further treatment (Health Council, 2025b). However, the precise production process of industrially produced dairy and meat replacers based on legumes is not known, and thus whether lectins are still biological active in those replacers.

It should be noted that the step-wise approach for prioritisation was a pragmatic approach for which only data available for dairy and meat replacers were used. Therefore, it should not be regarded as a new methodology for prioritisation. Prioritisation of substances for risk assessment should be performed on a case-by-case basis, depending on the context of the research question.

4.8.3 *Uncertainties*

The number of dairy replacers subdivided by the respective characteristic ingredients (pea, rice etc.) that were analysed was small. This may have introduced uncertainty in the prioritisation at the level of the characteristic ingredient.

In case there were no analytical data for a substance in dairy and meat replacers available, the concentrations were calculated using concentration data in ingredients or, in several instances, in raw agricultural products. For example, isolated soy proteins can be used to produce soy-based meat alternatives. If no concentration data were available for isolated soy protein, the concentration was assumed equal to that in raw soy beans. Lack of processing factors for such processes may have resulted in an over- or underestimation of the true concentration in isolated soy proteins and subsequently of the total exposure grade for prioritisation.

The use of standard recipes may cause uncertainty in the prioritisation, since many different recipes exist.

The selection of the characteristic ingredients was based on products on the market between 2018 and 2023. The replacer market is innovative, resulting in new products with characteristic ingredients different from the ones presented in this report. Other characteristic ingredients may result in different exposure profiles. Monitoring of trends in ingredients of replacers can provide insight into possible new risks.

4.9 Conclusion prioritisation

The process for prioritisation resulted in:

1. Six substances/substance groups for which additional analytical analyses are needed before a further assessment can be performed are:
    - AOH and AME in dairy and meat replacers (using a sensitive analytical method)

  - Aflatoxins in dairy and meat replacers (using a sensitive analytical method)
  - T-2 and HT-2 toxins in milk (drink) replacers (using a sensitive analytical method)
  - DON and metabolites in dairy replacers (using a sensitive analytical method)
  - Erucic acid in rapeseed oil-containing meat replacers for dinner
  - PAHs in dairy replacers based on almond and oat
2. Two substances for which no dairy and meat substitution scenarios can be performed due to the absence of a recent dietary exposure assessment:
  - GEs
  - MOAH
3. Two substances for which dairy and meat substitution scenarios can be performed once a dietary exposure assessment has been performed within the CoVo project:
  - Acrylamide
  - Inorganic arsenic
4. Two substances for which dairy and meat substitution scenarios can be performed due to the presence of a recent dietary exposure assessment:
  - Lead
  - Cadmium

The exposure assessment for lead and cadmium is presented in the next chapter.

5 Dietary exposure assessment of cadmium and lead in dairy and meat replacers

In Chapter 4 a rough estimate of the dietary exposure to cadmium and lead via the consumption of dairy and meat replacers was obtained by using standard portions of and mean concentration values in replacers. The baseline exposure was based on the exposure assessments of Boon et al. (2016 and 2022) and Sprong et al. (2015). During the current project, datasets that can be used for the dietary exposure assessment of cadmium and lead from all food sources (including drinking water) using the food consumption data of DNCF 2019-2021 were prepared in the Wheal of Five project and a dietary exposure assessment using these data will be published within the PARC Partnership for the Assessment of Risks from Chemicals (project). This means that a more refined dietary exposure assessment using substitution scenarios for dairy and/or meat by replacers can be performed for cadmium and lead. This chapter describes these assessments. First the methodology is described in Section 5.1, followed by the results in Section 5.2 and a discussion in Section 5.3. Finally, Section 5.4 describes the conclusion of the assessment.

5.1 Dietary exposure assessment methodology

The Wheal of Five datasets comprised food consumption data based on the DNFCS 2019-2021, concentration data of cadmium and lead in foods based on data from KAP and a linkage between the food and concentration data. Baseline dietary exposure assessments for cadmium and lead were performed using these datasets. The Wheal of Five datasets are described in more detail below (Sections 5.1.1 to 5.1.3). Substitution scenarios for dairy and/or meat replacers and the cadmium and lead concentrations used in these scenarios are described in Section 5.1.4. The dietary exposure calculations are described in Section 5.1.5.

5.1.1 Food consumption data

Food consumption data of the DNFCS 2019-2021 were used. See Section 2.1 for a detailed description. Consumption data of 1- to 3-year-olds and adults were used for the exposure assessment.

5.1.2 Concentration data

Concentration data for cadmium and lead were obtained from KAP and REWAB (years 2019 to 2023) and WFSR (years 2020, 2024 and 2025). Section 4.3.1 provides a detailed description of the databases. Data cleaning steps are described in Appendix 4. The concentration dataset contains, besides quantified concentrations, also concentrations reported as non-quantifiable (below the limit of quantification; <LOQ). For exposure assessments, the values below the LOQ were replaced with a concentration equal to ½ LOQ, typical for a middle bound scenario (EFSA 2010). Appendix 11 shows the cadmium and lead concentration data used for the baseline exposure assessments. Table 5.1 shows the concentrations used for the dairy and meat replacers.

Table 5.1 Mean concentration, number of samples (N) analysed and the percentage of samples with a value above the limit of quantification (LOQ) of replacers used in the substitution scenarios applied to the exposure assessments of cadmium and lead

Replacer	**Characteristic ingredient**	**Mean concentration (mg/kg)[a,b]**	**N**	**% >LOQ**
Cadmium				
Milk (drink)	Soy	0.004	7	100
Yoghurt[c]	Soy	0.004	7	100
Cheese	Almond	0.0024	13	100
Meat replacer for dinner	Soy	0.020	21	100
Pâté	Wheat	0.0032	30	10
Slices	Wheat	0.0079	30	10
Lead				
Milk (drink)	All replacers had the same lead concentration	0.0024	24	0
Yoghurt	All replacers had the same lead concentration	0.0024	24	0
Cheese	Coconut oil	0.0014	11	100
Meat replacer for dinner	Soy	0.013	21	33
Pâté	Pea	0.003	77	32
Slices	Pea	0.005	4	0

[a] Middle bound scenario in which values below the LOQ are assumed to equal the value of the LOQ.
[b] Highest mean concentration found across the different types of products (e.g. soy-based, rice-based etc) was used for all replacers.
[c] Values of milk (drink) replacers were taken for yoghurt replacers.

5.1.3 *Linking food to concentration data*

To calculate the chronic exposure to cadmium and lead, concentration data should be linked to the consumption data. For some foods, concentration data specific for the consumed foods were available (e.g. milk (drink) replacers and meat replacers for dinner). However, for several (composite) foods, only concentration data were available for ingredients of those foods or even for the raw agricultural commodities (RACs;e.g. soybeans instead of soybean proteins). Therefore, a model is needed that converts consumed foods to the level of the ingredients or RACs. The conversion program agricultural products, CPAP, converts consumed foods into their amount(s) of RAC(s) (Van Dooren, 1995). CPAP was used to link food consumption data to concentration data. If no concentration data were available for a certain RAC, the concentration of all RACs of the same hierarchical food group was used (e.g. strawberry was linked to berries and small fruits (blueberries, gooseberries, mulberries and grapes)).

5.1.4 *Scenarios*

In the exposure assessment, the following scenarios were addressed:

1. *Baseline scenario*. In this scenario, the current exposure to cadmium and lead via all foods (including dairy, meat and their replacers) and drinking water by the total population is assessed. In DNFCS 2019-2021, 96% of the total population consumed dairy or dairy replacers and 86% of the population consumed meat or meat replacers. Since the majority of the population consumed dairy, meat or their replacers , the total population rather than consumers only is considered in the assessment.
2. *Dairy substitution scenario*. In this scenario, all consumptions of milk, milk drinks, yoghurt and cheese (the most frequently consumed dairy products) were substituted with replacers. Since the mean concentration of cadmium varied between the replacers, the dairy products were substituted by the replacer with the highest mean concentration. For example, soy drink had higher cadmium concentrations compared to the other characteristic ingredients almond, coconut, oat, pea and rice (Table 4.5); therefore, the cadmium concentrations of soy drink were used as a worst case. Table 5.1 shows the replacers and the mean concentrations used in the assessment.
3. *Meat substitution scenario.* In this scenario, the consumptions of all hot and cold meat products were substituted with replacers. Meat products likely to be eaten for dinner were substituted with meat replacers for dinner, pâté and liver sausage were substituted with pâté replacers and all other cold cuts were substituted with slices replacers. As for the dairy substitution scenario, the replacer with the highest lead or cadmium concentration was used for the replacement (Table 5.1).
4. *Dairy and meat substitution scenario*. This scenario combines the dairy substitution and meat substitution scenarios.

5.1.5 *Dietary exposure calculation*

The chronic dietary exposure was assessed using the observed individual mean (OIM) module of the Monte Carlo Risk Assessment (MCRA) tool version 10.2.[5] The OIM model calculates the dietary exposure to a substance for each person in the food consumption database. For this, each consumed portion food per individual is multiplied with the average concentration of the substance in this food. For each consumption day, the dietary exposure to the substance via all foods is summed. This results in the dietary exposure per individual and per consumption day. Next, the exposure per individual is averaged over the number of consumption days in the food consumption database. For DNFCS 2019-2021, two consumption days were available. Subsequently, the average daily exposure is divided by the individual’s body weight. This is done for all individuals in the food consumption database, which results in a dietary exposure distribution from which the exposure statistics (mean and 95th exposure percentiles) were obtained.

The bootstrapping approach was used to quantify sampling uncertainty in food consumption caused by a limited sampling size (Efron, 1979; Efron and Tibshirani, 1993). This re-samples (with replacement) the

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[5] https://mcra.rivm.nl

original food consumption dataset to obtain a bootstrap of n observations. In the present calculation, we performed an uncertainty analysis using 100 re-sampling cycles with 10,000 iterations. This yielded 100 alternative exposure distributions, which might have been obtained during sampling from the population of interest. The mean and P95 were estimated for each of those 100 alternative exposure distributions, yielding 100 alternative exposure statistics. The median value of these 100 alternative exposure statistics (so the median of 100 alternative means and the median of 100 alternative P95s) was regarded as the best estimate, In addition, a 95% uncertainty interval around the best estimate exposure estimates were obtained from those 100 alternative exposure statistics. It should be noted that for the assessments the mean concentration of foods was used and not the whole range of concentration data for the particular food. Therefore, uncertainty around the concentration data could not be taken into account by using the bootstrap approach.

MCRA also provided information on the contribution of foods to the total exposure. If the contribution of a replacer to the total exposure was 5% or more, the replacer was considered as a main contributor to exposure.

To assess whether a substitution scenario may result in a statistically significant change in exposure compared with the baseline exposure, the uncertainty intervals around the best estimate of an exposure statistic (mean, P95) were compared. In case the confidence intervals did not overlap, the change in exposure was considered significant.

5.2 Dietary exposure assessment results

5.2.1 Cadmium

Table 5.2 presents the results of the cadmium exposure assessment for the population aged 1-3 years and the adult population. These population groups were selected because they represent two exposure boundaries, since 1- to 3-year-olds usually have the highest exposure due to a high food intake per kg body weight and adults usually have a lower exposure.

The best estimates of the baseline cadmium exposure via food and drinking water varied between 0.13 and 0.70 mg/kg bw per day, depending on the age group and the exposure percentile. If all milk, milk drink, yoghurt and cheese consumptions were substituted with that of their replacers, the cadmium exposure increased slightly (approximately 10-20% depending on the exposure statistics and age group). A significant increase in cadmium exposure was observed for the mean cadmium exposure in both age groups, but not for the population with the 5% highest exposure (P95).

When all hot (dinner meat) and cold meat products (pâté and slices) were substituted with replacers, the best estimate of cadmium exposure also slightly increased compared with the baseline exposure, but less than for dairy substitution (approximately 5-10%). Comparing the uncertainty intervals showed that significance was only obtained for the mean exposure of the adult population.

When both dairy and meat products were substituted, the cadmium exposure increased again slightly compared with the background exposure (approximately 15-25%), with significance obtained for all exposure estimates in both age groups.

Table 5.2 Baseline dietary exposure of cadmium by the total Dutch population aged 1-3 year old and adults and expected cadmium exposure if all dairy products and/or meat products are substituted with replacers. Values in bold were significantly different from baseline exposure. A significant difference is obtained if uncertainty intervals around the best estimate of the baseline exposure did not overlap the uncertainty intervals of the best estimate of the substitution scenario

Scenario	**Exposure (µg/kg bodyweight)**[a]			
	1-3 year		**Adults**	
	Mean	**P95**	**Mean**	**P95**
Baseline[b]	0.41[f] (0.39-0.42)	0.70 (0.64-0.75)	0.13 (0.13-0.13)	0.23 (0.23-0.25)
Dairy substitution[c]	**0.49**[g] (0.48-0.51)	0.79 (0.74-0.87)	**0.14** (0.14-0.14)	0.25 (0.24-0.26)
Meat substitution[d]	0.44 (0.42-0.45)	0.75 (0.68-0.78)	**0.14** (0.14-0.15)	0.25 (0.24-0.27)
Dairy and meat substitution[e]	**0.52** (0.51-0.54)	**0.84** (0.78-0.92)	**0.16** (0.15-0.16)	**0.26** (0.26-0.28)

[a] The middle bound scenario, in which values below the limit of quantification are assumed to equal half the value of the LOQ, was used to assess the dietary exposure.
[b] Current cadmium exposure, assessed using the Dutch National Food Consumption Survey 2019-2020, the KAP database (2019-2023), the REWAB database (2019-2023) for all foods except replacers and analytical measurements of cadmium in milk (drink) replacers, yoghurt replacers and meat replacers for dinner performed by WFSR (2024 and 2025).
[c] Scenario in which all consumptions of milk, milk drinks, yoghurt and cheese were substituted with replacers.
[d] Scenario in which all consumptions of hot and cold meat products were substituted with replacers.
[e] Scenario in which all consumptions of milk, milk drinks, yoghurt, cheese, and hot and cold meat products were substituted with replacers.
[f] Values are best estimates, values between brackets indicate the uncertainty around the best estimate.
[g] Values in bold were significantly different from baseline exposure. A significant difference is obtained if uncertainty intervals around the best estimate of the baseline exposure did not overlap the uncertainty intervals of the best estimate of the substitution scenario.

The contribution to the total dietary exposure to cadmium is shown in Table 5.3. A contribution to the total exposure of at least 5% is considered a significant contribution. For the baseline exposure, dairy, meat and their replacers contributed less than 5% to the exposure. If all milk, milk drinks, yoghurt and cheese were replaced, milk (drink) replacers became a significant contributor to the cadmium exposure, particularly for 1- to-3-year-olds (17.9%). Similarly, if all meat products were replaced, meat replacers for dinner became a significant contributor to the exposure to cadmium (9.9% and 12.9% for 1- to-3-year-olds and adults, respectively). Similar results were obtained if both dairy and meat consumption were substituted.

Table 5.4 shows the contribution of the food products to the exposure of subjects with an exposure larger than the P95 dietary cadmium exposure. Replacers did not contribute significantly to the upper 5% of cadmium exposure. When dairy was substituted with replacers, milk (drink) replacers became a significant source of cadmium in 1- to-3-year-olds, but not in adults. In the meat substitution scenarios, meat replacers for dinner became an important contributor to cadmium exposure in both 1- to-3-year-olds and adults. Replacers contributed less to the dietary cadmium exposure of subjects at the upper 5% of exposure compared to the total population. Possibly other food sources may be more important contributors to the cadmium exposure for subjects with an exposure higher than the P95.

Table 5.3 Contributors to the total dietary cadmium exposure[a] for the baseline exposure of the total Dutch population aged 1-3 years and adults and the expected cadmium exposure if all dairy and/or meat products are substituted with replacers

Type of products	**Contribution to exposure (%)**			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
1-3 year olds				
Dairy products	4.1	0	3.8	0
Milk (drink) replacer	1.3	**17.9[b]**	1.2	**16.9**
Yoghurt replacer	0.08	3.2	0.08	3.0
Cheese replacer	0.002	0.5	0.002	0.5
Meat	3.8	3.2	0	0
Meat replacer for dinner	0.5	0.4	**9.9**	**8.3**
Pâté replacer	0.01	0.01	0.1	0.1
Slices replacer	0.002	0.002	1.0	0.8
Adults				
Dairy products	2.5	0	2.2	0
Milk (drink) replacers	0.4	**6.3**	0.4	**5.7**
Yoghurt replacer	0.2	3.6	0.1	3.35
Cheese replacer	0.002	0.8	0.002	0.7
Meat	3.6	3.4	0	
Meat replacer for dinner	1.1	1.0	**12.9**	**12.0**
Pâté replacer	0.02	0.02	0.08	0.07

Type of products	**Contribution to exposure (%)**			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
Slices replacer	0.004	0.004	1.2	1.1

[a] The middle bound scenario, in which values below the limit of quantification are assumed to equal half the value of the LOQ, was used to assess the dietary exposure.
[b] Percentages in bold indicate that those foods contributes significantly (i.e. five percent or more) to the dietary exposure.

Table 5.4 Contributors to the upper 5% dietary cadmium exposure for baseline exposurea of the total Dutch population aged 1-3 years and adults and the expected cadmium exposure if all dairy and/or meat products are substituted with replacers

Type of products	**Contribution to exposure (%)**			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
1-3 year olds				
Dairy products	1.9	0	1.9	0
Milk (drink) replacer	3.0	**13.1**[b]	2.7	**12.7**
Yoghurt replacer	0.2	3.3	0.2	3.0
Cheese replacer	0.009	0.3	0.008	0.3
Meat	1.6	1.5	0	0
Meat replacer for dinner	0.5	0.4	**7.1**	**6.7**
Pâté replacer	0.02	0.02	0.05	0.05
Slices replacer	0	0	0.5	0.4
Adults				
Dairy products	1.7	0	1.5	0
Milk (drink) replacer	0.8	4.7	0.7	4.1
Yoghurt replacer	0.2	2.4	0.27	2.4
Cheese replacer	0.0001	0.4	0.0001	0.4
Meat	1.6	1.4	0	0
Meat replacer for dinner	1.5	1.4	**8.7**	**8.2**
Pâté replacer	0.02	0.02	0.04	0.04

Type of products	**Contribution to exposure (%)**			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
Slices replacer	0	0	0.6	0.6

The middle bound scenario, in which values below the limit of quantification are assumed to equal half the value of the LOQ, was used to assess the dietary exposure.

[b] Percentages in bold indicate that those foods contributes significantly (i.e five percent or more) to the dietary exposure.

5.2.2 *Lead*

The best estimate of the baseline dietary exposure to lead varied from 0.16-0.62 µg/kg bw per day, depending on the age group and the exposure statistics (Table 5.5). If all milk, milk drinks, yoghurt and cheese were substituted with replacers, the exposure slightly increased (around 8%) in 1- to 3-year-olds, but not in adults. A significant increase, as assessed by non-overlapping uncertainty intervals, was only observed for the mean lead exposure in 1- to 3-year-olds. Substitution of all meat consumption with replacers did hardly affect the exposure to lead. If the dairy and meat substitution scenario was combined, the lead exposure increased with 10-20% in 1- to 3-year-olds (only significant for the mean exposure) and again did not affect the exposure of the adults.

Table 5.5 Baseline exposure of lead by the total Dutch population aged 1-3 years and adults and expected lead exposure if all dairy and/or meat products are substituted with replacers

Scenario	**Exposure (µg/kg bodyweight)[a]**			
	1-3 year		**Adults**	
	Mean	**P95**	**Mean**	**P95**
Baseline[b]	0.37 (0.36-0.39)	0.62 (0.59-0.68)	0.16 (0.15-0.16)	0.30 (0.28-0.31)
Dairy substitution[c]	**0.42**[f] (0.40-0.43)	0.67 (0.64-0.72)	0.16 (0.16-0.16)	0.30 (0.28-0.32)
Meat substitution[d]	0.39 (0.38-0.41)	0.64 (0.62-0.68)	0.16 (0.16-0.17)	0.30 (0.29-0.32)
Dairy and meat substitution[e]	**0.44** (0.42-0.45)	0.69 (0.66-0.74)	0.17 (0.16-0.17)	0.31 (0.29-0.32)

[a] Middle bound scenario in which values below the LOQ are assumed to equal half the value of the LOQ.

[b] Current lead exposure, assessed using the Dutch National Food Consumption Survey 2019-2020, the KAP database (year 2019-2023), the REWAB database (years 2019-2023) and analytical measurements of lead in milk (drink) replacers, yoghurt replacers and meat replacers for dinner performed by WFSR (2024 and 2025).

[c] Scenario in which all consumptions of milk, milk drinks, yoghurt and cheese were substituted with replacers.

[d] Scenario in which all consumptions of hot and cold meat products were substituted with replacers.

[e] Scenario in which all consumptions of milk, milk drinks, yoghurt, cheese, and hot and cold meat products were substituted with replacers.

[f] Values in bold were significantly different from baseline exposure. A significant difference is obtained if uncertainty intervals around the best estimate of the baseline exposure did not overlap the uncertainty intervals of the best estimate of the substitution scenario.

Table 5.6 shows the contribution of dairy, meat and their replacers to the total lead exposure. None of these foods had a significant contribution to exposure since the percentage contribution to the total lead exposure was less than 5%. When all milk, milk drinks, yoghurt and cheese consumption was replaced with alternatives, milk (drink) replacers became a significant contributor to the lead exposure in 1- to 3-year-olds (12.7%) but not in adults. When all meat products were replaced, meat replacers for dinner became an important contributor to the lead exposure in both 1- to 3-year-olds and adults (7.5 and 7.7%, respectively).

The contribution of dairy, meat and their replacers to the upper 5% of the lead exposure is shown in Table 5.7. The contribution of dairy and meat to the lead exposure in the baseline scenario was approximately a factor 2 lower compared with the total exposure. The contribution via replacers did not largely differ between the total exposure and the upper 5% exposure. When dairy was substituted, only milk (drink) replacers became a significant contributor to the exposure in the 1- to 3-year-olds, but not in adults. In the meat substitution scenario, meat replacers did not become a significant contributor to the exposure.

Table 5.6 Contributors to the total dietary lead exposure for the baseline exposure of the total Dutch population aged 1-3 years and adults and the expected cadmium exposure if all dairy and/or meat products are substituted with replacers[a]

Type of products	**Contribution to exposure (%)**			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
1-3 year olds				
Dairy products	4.8	0	4.6	0
Milk (drink) replacer	0.9	**12.7**[b]	0.8	**12.2**
Yoghurt replacer	0.05	2.3	0.05	2.2
Cheese replacer	0.001	0.3	0.001	0.3
Meat	3.3	2.9	0	0
Meat replacer for dinner	0.4	0.3	**7.5**	**6.8**
Pâté replacer	0.01	0.01	0.1	0.1
Slices replacer	0.001	0.001	0.7	0.6
Adults				
Dairy products	2.1	0	1.9	0
Milk (drink) replacer	0.2	3.3	0.2	3.1

Type of products	Contribution to exposure (%)			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
Yoghurt replacer	0.06	1.9	0.06	1.8
Cheese replacer	0.0008	0.4	0.0008	0.4
Meat	3.0	2.8	0	0
Meat replacer for dinner	0.6	0.6	**7.7**	**7.5**
Pâté replacer	0.01	0.01	0.06	0.06
Slices replacer	0.002	0.002	0.7	0.7

[a] Middle bound scenario in which values below the LOQ are assumed to equal half the value of the LOQ.
[b]Percentages in bold indicate that those foods contributes significantly (i.e. five percent or more) to the dietary exposure.

Table 5.7. Contributors to the P95 dietary lead exposure for the baseline exposure of the total Dutch population aged 1-3 years and adults and the expected cadmium exposure if all dairy and/or meat products are substituted with replacers

[a]Type of products	Contribution to exposure (%)			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
1-3 year olds				
Dairy products	2.4	0	2.4	0
Milk (drink) replacer	1.3	**8.4**[b]	1.2	**8.8**
Yoghurt replacer	0.07	1.4	0.04	1.3
Cheese replacer	0	0.2	0.0003	0.2
Meat	1.5	1.5	0	0
Meat replacer for dinner	0.2	0.1	4.4	4.6
Pâté replacer	0.02	0.01	0.03	0.02
Slices replacer	0	0	0.4	0.4
Adults				
Dairy products	0.8	0	0.9	0
Milk (drink) replacer	0.4	1.4	0.4	1.4

[a]**Type of products**	**Contribution to exposure (%)**			
	Baseline exposure	**Dairy substitution**	**Meat substitution**	**Meat and dairy substitution**
Yoghurt replacer	0.09	1.3	0.09	1.3
Cheese replacer	0.0004	0.2	0.0004	0.2
Meat	1.2	1.1	0	0
Meat replacer for dinner	0.8	0.8	4.0	3.9
Pâté replacer	0.01	0.01	0.02	0.02
Slices replacer	0	0	0.4	0.31

[a] Middle bound scenario in which values below the LOQ are assumed to equal half the value of the LOQ.
[b] Percentages in bold indicate that those foods contributes significantly (i.e five percent or more) to the dietary exposure.

5.3 Discussion

5.3.1 *Comparison to previous dietary exposure assessments*

For cadmium, the baseline dietary exposure estimates for 1- to 3-year-olds based on the datasets from the Wheal of Five project were comparable to the exposure estimates used for the prioritisation taken from Boon et al. (2022) (Table 5.8). For adults, however, a factor two lower dietary exposure was found in the current study compared with the assessment performed in 2015 (Sprong et al., 2015). If the new exposure estimates were used in the process for prioritisation, the total exposure grade would have been lower for adults but not for 1- to 3-year-olds. Therefore, using the new exposure assessment, cadmium would still be a priority substance based on the exposure in 1- to 3-year olds.

For lead, the dietary exposure estimate for 1- to 3-year-olds was slightly higher compared with a recent total diet study in 1- to 2-year-olds (Boon et al., 2022). For adults, the current estimates were approximately a factor two lower than those assessed in 2016 (Boon et al., 2016). The use of the new exposure estimates in the process for prioritisation would not have resulted in other total exposure grades.

Differences in food consumption data, concentration data, food matching and exposure assessment methodology may account for the differences between the previous and current assessment.

Table 5.8 Comparison of the current dietary exposure to cadmium and lead (µg/kg bodyweight per day) with those assessed in the past

	Current Mean	P95	Previous Mean/P50	P95	Reference
Cadmium					
1-3 years	0.41	0.70	0.37[a]	0.72	Boon et al. 2022[b]
Adults	0.13	0.23	0.26[c]	0.48	Sprong et al. 2015[d]
Lead					
1-3 years	0.37	0.62	0.25[a]	0.47	Boon et al. 2022[b]
Adults	0.16	0.30	0.41[a]	0.74	Boon et al. 2016[e]

[a] P50
[b] Boon et al. (2022) estimated the dietary exposure to cadmium and lead in 1- to 2-year-olds using a total diet study and for the lower bound (values below LOQ are assumed to be 0) and upper bound (values below the LOQ are assumed to be equal the value of the LOQ) scenarios. Here the average of the lower bound and the upper bound is presented as a proxy for the middle bound scenario.
[c] Mean
[d] Sprong et al. (2015) assessed the dietary exposure to cadmium in 2- to 6-year-olds and adults at the middle bound scenario.
[e] Boon et al. (2016) estimated the dietary exposure to lead in 2- to 6-year-olds and adults at the middle bound scenario.

5.3.2 *Concentrations of cadmium and lead in replacers*

The changes in exposure calculated in the dairy and/or meat substitution scenario were based on the concentrations used for the replacers. In the MB scenario, values below the LOQ were assumed to equal half the value of the LOQ. In case many samples are below the LOQ, the exposure assessment can be driven by the value of the LOQ. Therefore, the impact of samples with values below the LOQ is discussed below. In addition, concentrations are compared with those found in literature, if available. Also the impact of using the replacers with the highest concentration as a worst case scenario is discussed.

Cadmium

For cadmium, all measurements in dairy replacers were above the LOQ (Table 5.1). Therefore, the increase in cadmium exposure found in this scenario was not driven by the value of the LOQ. Comparable MB mean cadmium concentrations in soy-based milk (drink) replacers were observed by others (0.004 mg/kg in our study; 0.003 mg/kg in Redan et al., 2023 and Astolfi et al., 2020), indicating that realistic concentrations for soy-based milk (drink) replacers were used in the assessment.

For the meat substitution scenario, all measurements in meat replacers for dinner were above the LOQ, while only 10% of the values for pâté replacers and slices. MB mean concentrations were comparable with those obtained by NVWA/WFSR in 2020 indicating that the cadmium concentration in meat replacers found in the current project is realistic. Since pâté replacers and slices were minor contributors to the cadmium exposure, the increased exposure to cadmium in the substitution scenario is not largely affected by the value of the LOQ.

Lead
For lead, the results of the dairy substitution scenarios are affected by the value of the LOQ, since none of the values for milk and milk drink replacers and yoghurt replacers were above the LOQ. Other studies showed that only a few measurements in milk (drink) replacers had lead values above the LOQ (almond, cashew and coconut-based milk (drink) replacers; Redan et al., 2023). In literature, MB mean values in milk replacers were comparable with the one used in our study (0.0024 mg/kg vs. 0.004 mg/kg in Redan et al., (2023) and 0.0027 mg/kg in Astolfi et al., (2020)). Values for cheese replacers were above the LOQ, thus the calculated exposure is not affected by the value of the LOQ. Cheese replacers were only minor contributors to the lead exposure in the dairy substitution scenarios and thus will have a minor impact on the exposure assessment.

Regarding meat replacers, 33% of the meat replacers for dinner had values above the LOQ. MB mean values in meat replacers in our study were comparable to those obtained by WFSR/NVWA in 2020 (15% below LOQ).

Uncertainty in concentration data
In the dietary exposure assessments, the mean concentration of substances in dairy and meat replacers and of other foods were used as input for the dietary exposure assessment. Therefore, bootstrapping to assess the uncertainty in concentration data could not be taken into account. This means that the uncertainty intervals around the best estimate presented in Tables 5.2 and 5.5 could have been larger if bootstrapping of concentration data was included. This introduces uncertainty around the interpretation of significant differences, because a slightly larger interval could have resulted in differences that would no longer be regarded as significant.

5.3.3 Assessment scenario

In the dairy substitution scenario, the focus was on milk (drink) replacers, yoghurt replacers and cheese replacers, since these dairy products are most frequently consumed by the Dutch population. Neglecting consumption of replacers of desserts, ice cream, cream and coffee creamer may have resulted in a small under- or overestimation of the dietary exposure to cadmium and lead in the dairy substitution scenarios. Consumption of fish replacers was also neglected in the meat substitution scenario, which also may have caused a small under- or overestimation of the dietary exposure .

It was also assumed that 100% of milk (drinks), yoghurt, cheese and meat was substituted by replacers. While this exposure scenario is relevant for consumers only, it is an overestimation of the exposure of consumers who will partly substitute their diet. For example, the increase in cadmium and lead exposure will be lower when considering a shift to a diet consisting of 60% plant-based and 40% animal-based proteins as aimed for in the report of the Dutch Heath Council (2023).

Desserts, ice cream and cream and coffee creamers were not considered in the exposure scenarios. Since consumption of these foods is much lower compared with milk(drinks), yoghurt and cheese, neglecting substitution of desserts, ice cream, cream and coffee creamers most likely resulted in a small underestimation of the dietary exposure to cadmium and lead.

It should be noted that the assessed substitution scenarios are worst case, assuming that all dairy and/or meat consumptions are substituted with the type of replacers with the characteristic ingredient which had the highest cadmium or lead concentration (see Table 5.1). If consumers vary their milk (drink) replacers and meat replacers with another characteristic ingredient, the impact of the replacers on the cadmium and lead exposure will be lower.

Overall, the dietary exposure to lead and cadmium is likely overestimated in the substitution scenarios.

5.4 Conclusion exposure assessment

Substitution of dairy and meat with replacers may have a small impact on the dietary exposure to cadmium and a limited impact in the dietary exposure to lead. It should be noted that the dietary exposure to lead and cadmium is likely overestimated in the substitution scenarios.

6 Conclusions

The aim of this report was to investigate whether the consumption of industrially produced dairy and meat replacers increases the dietary exposure to certain hazardous substances in order to prioritise substances for monitoring and risk assessment. To this end, three questions were answered discussing 1) representative consumption amounts of industrially processed dairy and meat replacers for children aged 1 – 3 years and adults in the Netherlands, 2) the possible presence of hazardous substances in industrially processed dairy and meat replacers, and 3) the prioritisation of these substances for future monitoring and risk assessment.

The Dutch Food Consumption Survey 2019-2021 shows that the most frequently consumed industrially produced dairy replacers are replacers of milk and milk drinks, yoghurt and cheese. The major ingredients of these products are almond, coconut (oil), oat, pea, rice, soy, cashew nut, starch and water. For industrially produced meat replacers, these are replacers of dinner meat, pâté and slices. The major ingredients of these products are pea, soy, wheat, vegetable oil (undefined, soy or sunflower), egg protein and water. Only a small part of the population consumed these dairy and meat replacers. Current consumption statistics of the total population, who may consume dairy and meat replacers once in a while, is an underestimation for frequent consumers of these products (consumers only). Therefore, we only looked at the consumption portions of consumers of these dairy and meat replacers and not at consumption statistics of the total population. Consumption sizes of portions of dairy and meat replacers of consumers only were in the same order of magnitude as dairy and meat.

In these most frequently consumed industrially produced dairy and meat replacers, 33 (groups) of substances were identified as toxicologically relevant, amongst others mycotoxins, plant toxins, (heavy) metal(loid)s, persistent organic pollutants and process contaminants. This list was further narrowed down to obtain the priority substances for which a dietary exposure assessment is needed and could be performed.

For twelve (groups of) substances an exposure assessment is needed: 1) the Alternaria toxins AOH and AME, 2) aflatoxins, 3) T-2 and HT-2, 4) DON and metabolites, 5) inorganic arsenic, 6) lead, 7) cadmium, 8) erucic acid, 9) PAHs, 10) GEs, 11) acrylamide and 12) MOAH. For six of them (AOH and AME, aflatoxins, T-2 and HT-2 toxins, DON and metabolites, erucic acid and PAHs) additional sensitive chemical analyses are needed to obtain reliable concentration data before they can be considered for an exposure assessment.

For four other substances, i.e. GEs, MOAH, acrylamide and inorganic arsenic , the dietary exposure could not be assessed within the current project due to the lack of recent exposure data. For the latter two substances, substitution scenarios can be performed once exposure assessments as part of another project of RIVM financed by the Ministry of Health, Welfare and Sport (the CoVo project) are finalised.

For two substances, lead and cadmium, substitution scenarios were performed in the current report due to the availability of a recent exposure assessment and concentration data in replacers. Substitution of dairy and meat with industrially-produced dairy and meat replacers showed that this may have a small impact on the dietary exposure to cadmium and a limited impact in the dietary exposure to lead. It should be noted though that the dietary exposure to both substances is likely overestimated in the substitution scenarios.

Certain substances more typical for industrially-produced plant-based replacers (enniatins, isoflavones, lectins and protease inhibitors), for which higher dietary exposures could be expected when a shift towards more plant-based takes place, could not be assessed due to the lack of a TRV and/or an analytical method. For these substances, analytical methods and TRVs need to be developed to be able to assess the health risks of these relevant substances. Further, industrially-produced plant-based replacers are an innovative field and many new products based on different ingredients are to be expected, each having their own possible impact on dietary exposure to substances. Therefore, monitoring changes in replacers on the market may help to prioritise substances that require attention in the future.

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List of acronyms

3-MCPD	3-Monochloropropanediol
AFB$_1$	Aflatoxin type B$_1$
AFB$_2$	Aflatoxin type B$_2$
AFG$_1$	Aflatoxin type G$_1$
AFG$_2$	Aflatoxin type G$_2$
AFM$_1$	Aflatoxin type M$_1$
AGE	Advanced glycation end product
AME	Alternariol methyl ether
AOH	Alternariol
BuRo	Office for Risk Assessment & Research of the Netherlands Food and Product Safety Authority
Cd	Cadmium
CEL	Carboxyethyl-lysine
CML	Nε-carboxymethyllysine
DON	Deoxynivalenol
DNFCS	Dutch National Food Consumption Survey
EFSA	European Food and Safety Authority
FB$_1$	Fumonisin type B$_1$
FB$_2$	Fumonisin type B$_2$
FB$_3$	Fumonisin type B$_3$
FB$_4$	Fumonisin type B$_4$
GE	Glycidyl fatty acid
GNPD	Mintel’s Global New Product Database
iAs	Inorganic arsenic
iHg	Inorganic mercury
KAP	*Kwaliteitsprogramma Agrarische Producten* (Quality Program Agricultural Products)
LEDA	Branded Food Label Database
MG	Methyl-glyoxal
MOAH	Mineral oil aromatic hydrocarbon
MOSH	Mineral oil saturated hydrocarbon
NEVO	*Nederlands Voedingsstoffenbestand* (Dutch Food Composition database)
Ni	Nickel
NVWA	Netherlands Food and Product Safety Authority
OTA	Ochratoxin A
PAH	Polyaromatic hydrocarbon
PCB	Polychlorinated biphenyls
Pb	Lead
PFAS	Per and polyfluoro alkyl substances
REWAB	*Registratie opgaven van Drinkwaterbedrijven* (monitoring results drinking water companies)
TA	Tropane alkaloid
T-2 and HT-2	T-2 toxin and H-T2 toxin
TeA	Tenuazonic acid
TEN	Tentoxin
WFSR	Wageningen Food Safety Research
ZEA	Zearalenone

Appendix 1 Overview of the substances remained per prioritisation steps

This Appendix provides an overview of the substances during the 6 prioritisation steps described in Figure 1. Each sheet in the excel file represents one step of the process for prioritisation, except for step 5 and 6.The outcome of those steps is provided in different colours. In all other steps, excluded substances are indicated by strikethrough.

https://www.rivm.nl/bibliotheek/rapporten/2025-0163-appendix-1.xlsx

Appendix 2 Methods and analytical results of dairy and meat replacers – WFSR

Various substances were analysed in dairy and meat replacers. The results of which can be found in:
https://www.rivm.nl/bibliotheek/rapporten/2025-0163-appendix-2a.xlsx
https://www.rivm.nl/bibliotheek/rapporten/2025-0163-appendix-2b.xlsx

Methods used for the analyses are indicated below.

Heavy metals

Heavy metals nickel (Ni), copper (Cu), arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) were analysed in both dairy (n=45) and meat replacers (n=44) according to WFSR SOP-2514 using ICP-MS. In case total arsenic levels were found above the limit of quantification (LOQ), inorganic arsenic (iAs) was analysed as well according to WFSR SOP-2320 using HPLC-ICP-MS. All values were reported in mg/kg product.

Processing and other contaminants

The processing contaminants acrylamide, AGEs (including argpyrimidine, carboxyethyl-lysine (CEL), Nε-carboxymethyllysine (CML), methylglyoxal hydroimidazolones (MG-H), glyoxal hydroimidazolones (GH) and pentosidine), MCPD, GE as well as mineral oils (MOSH/MOAH) were analysed as indicated below.

Acrylamide

45 dairy replacers were analysed on acrylamide according to WFSR SOP-2153 using UPLC-MS/MS. Results were expressed in µg/kg product. The LOQ was 20 µg/kg product. The results of one product could not be reported because the sample was of insufficient quality for injection. The high content of spices, e.g. cinnamon, turmeric and black pepper in the sample affected this quality.

AGEs

The same dairy replacers were analysed on AGEs using LC-MS/MS. The method was developed in research projects but has not been validated yet. Due to differences in protein content, four individual analytical series were performed using different sample intake volumes. This led to different LOQ's in the individual series. GH and MG-H analytes were reported as the sum of the analytes and not based on their individual isomers. When the results did not meet accuracy acceptance criteria, no results could be reported (indicated as NR and highlighted in yellow in Appendix 2A). In case sample measurement criteria were not met, but the results were >LOQ, the results were reported as indicative value (highlighted in pink in Appendix 2A). In case sample criteria were not met, but results were clearly <LOQ, the sample was reported as <LOQ. Due to analytical problems in one of the measurements, ion ratios could not be determined. Ion ratio values are based on one matrix-matched standard series and thus should be interpreted as indicative values (highlighted in blue in Appendix 2A). The results were expressed in mg/kg product.

3-MCPD/GEs

A selection of 24 meat replacers for dinner representing the various product categories were analysed on 2- and 3-MCPDs and GEs according to WFSR SOP-2494 using GCMS. Both raw products and baked products were analysed and results were expressed in µg/kg fat. LOQs differed per compound and whether the sample was heated or not. The meat replacers were baked in a semi-professional kitchen at Wageningen University. A standard protocol was used for baking. This implied preheating a frying pan for 90 seconds with addition of 15 mL sunflower oil (Albert Heijn biologische zonnebloemolie, 1L). The products were fried according to the cooking instructions on the packaging. The products were cooled down to room temperature before transferring into zip-lock bags and storing in the freezer (-18 °C). Between preparing each of the products, the frying pan was cleaned thoroughly using dish soap, hot water and a cleaning brush after which it was dried using a clean towel. In order to calculate the MCPD/GEs levels per kg product, the fat percentage was used. For unheated products, the fat percentages as reported on the label were used. For heated products, the Weibull method was used to determine the fat%. Apart from that, the MCPD/GE levels in the sunflower oil used for baking was analysed. Fat uptake was estimated by subtracted the fat% as analysed in the heated product by the fat% as declared on the label. In total 5 tables were generated:

- MCPD/GEs levels in raw products, as analysed per kg fat
- MCPD/GEs levels in raw products, calculated per kg product (using fat percentage)
- MCPD/GEs levels in heated products, as analysed per kg fat
- MCPD/GEs levels in heated products, calculated per kg product (using fat percentage)
- MCPD/GEs levels in heated products, calculated per kg product (taking into account fat uptake from the sunflower oil used for baking)

Apart from the 24 meat replacers for dinner, thirteen ready-to-eat sandwich fillings (3 replacers for filet americain, 5 pâté and 5 slices) were analysed on MCPD/GEs using the same analytical method. Since these products are ready-to-eat, they were not heated. Results were reported in µg/kg fat. Like indicated above, the fat percentage as reported on the label was used to calculate the MCPD/GEs levels per kg product.

MOSH/MOAH

Since MOSH/MOAH were primarily expected in pâté, only these products were analysed according to WFSR SOP-2487 using LC-GC-FID. Results were expressed in mg/kg product. For both MOSH and MOAH the following groups of compounds were analysed: C10-C16, C16-C20, C20-C25, C25-C35 and C35-C50. LOQs differed per compound group but the combined LOQ for MOSH was established as 0.6 mg/kg and for MOAH 0.4 mg/kg. The results for MOSH and MOAH were obtained by adding the levels found for the different compound groups using a lower bound approach (i.e. assuming <LOQ = 0).

Natural toxins

Mycotoxins

Fumonisin was selected as potential relevant hazard in cheese replacers. A multi-method was used according to WFSR SOP-2604 using LC-MS/MS. This allowed reporting on a range of mycotoxins: aflatoxins (AFB1, AFB2, AFG1 and AFG2), ochratoxin A, enniatins (A, A1, B, B1), beauvericin, fumonisins (FB1, FB2, FB3 and FB4), DON, zearalenone, HT-2-toxin, T-2-toxin, alternariol, methyl-alternariol and sterigmatocystin. Levels were reported in µg/kg product. The LOQ differed per compound but for fumonisin it was established at 0.5 µg/kg product. One sample contained FB4 below the LOQ but above the lowest calibration level of 0.25 µg/kg product, i.e. analysed at 0.35 µg/kg product. Since FB4 is not regularly monitored as it is not required by the European Regulation, the level of 0.35 µg/kg was included in the reported results.

Plant toxins

The 44 meat replacers were analysed for the presence of tropane alkaloids (TAs) according to WFSR SOP-2314 using LC-MS/MS. The following TAs were analysed: atropine, scopolamine, anisodamine, anisodine, aposcopolamine and homatropine. Results were expressed in µg/kg product. The LOQ for all compounds was 1 µg/kg product. Apart from individual results, the sum of the most frequently occurring TAs (i.e. atropine and scopolamine) were reported as well as the sum of all analysed TAs using a lower bound approach (i.e. assuming <LOQ = 0).

Appendix 3 Overview of available substance concentration databases and their source

Table A3 Overview of available substance concentration data-bases and their source

	Dairy replacers			**Meat replacers**		
Substance	**Milk (drink)**	**Yoghurt**	**Cheese**	**For dinner**	**Pâté**	**Slices**
Heavy metals						
(i)As	WFSR	Taken from milk (drink) replacers	KAP/REWAB ingredients	WFSR	KAP/REWAB ingredients	KAP/REWAB ingredients
Cd	WFSR	Taken from milk (drink) replacers	KAP/REWAB ingredients	WFSR	KAP/REWAB ingredients	KAP/REWAB ingredients
(i)Hg	WFSR	Taken from milk (drink) replacers	NA	WFSR	NA	NA
Pb	WFSR	Taken from milk (drink) replacers	KAP/REWAB ingredients	WFSR	KAP/REWAB ingredients	KAP/REWAB ingredients
Ni	WFSR	Taken from milk (drink) replacers	KAP/REWAB ingredients	WFSR	KAP/REWAB ingredients	KAP/REWAB ingredients
*Mycotoxin*s						
Aflatoxins	WFSR	Taken from milk (drink) replacers	WFSR	KAP	KAP ingredients	KAP ingredients
Alternaria toxins	WFSR (AOH, AME and TEN)	Taken from milk (drink) replacers	WFSR (AOH, AME)	KAP ingredients (AOH, AME, TEN and TeA)	KAP ingredients (AOH, AME, TEN and TeA)	KAP ingredients (AOH, AME, TEN and TeA)
DON and metabolites	WFSR	Taken from milk (drink) replacers	WFSR	KAP	KAP ingredients	KAP ingredients
Enniatins	WFSR	Taken from milk (drink) replacers	WFSR	NA	NA	NA

	Dairy replacers			**Meat replacers**		
Substance	**Milk (drink)**	**Yoghurt**	**Cheese**	**For dinner**	**Pâté**	**Slices**
Ergot alkaloids	WFSR	Taken from milk (drink) replacers	WFSR	NA	NA	NA
Fumonisins	WFSR	Taken from milk (drink) replacers	WFSR	KAP	KAP ingredients	KAP ingredients
OTA	WFSR	Taken from milk (drink) replacers	WFSR	KAP	KAP ingredients	KAP ingredients
T-2 and HT-2	WFSR	Taken from milk (drink) replacers	WFSR	NA	NA	NA
ZEA	WFSR	Taken from milk drink replacers	WFSR	KAP	KAP ingredients	KAP ingredients
Plant toxins		Taken from milk (drink) replacers				
Cyanogenic glycosides	WFSR	Taken from milk (drink) replacers	Taken from milk (drink) replacers	NR	NR	NR
Erucic acid	NR	NR	NR	KAP ingredients	KAP ingredients	KAP ingredients
Lectins	NA	NA	NA	NA	NA	NA
Tropane alkaloids	WFSR	Taken from milk (drink) replacers	NA	WFSR	KAP ingredients	KAP ingredients
Glycoalkaloids	NA	NA	NA	NR	NR	NR
Protease inhibitors	NA	NA	NR	NA	NA	NA
Isoflavones	NA	NA	NR	NA	NA	NA
Process contaminants						
Acrylamide	WFSR	Taken from milk (drink) replacers	NA	WFSR	NA	NA
AGEs	WFSR	Taken from milk (drink) replacers	NR	NA	NR	NR
GE	NR	NR	NVWA	WFSR	WFSR	WFSR
3-MCPD	NR	NR	NVWA	WFSR	WFSR	WFSR

	Dairy replacers			**Meat replacers**		
Substance	**Milk (drink)**	**Yoghurt**	**Cheese**	**For dinner**	**Pâté**	**Slices**
PAHs	NR	NR	NVWA	KAP	KAP ingredients	KAP ingredients
Others						
MOSH	NR	NR	NA	KAP ingredients	WFSR	KAP ingredients
MOAH	NR	NR	NA	KAP ingredients	WFRS	KAP ingredients
Perchlorate	REWAB	REWAB	REWAB	REWAB	REWAB	REWAB
Nitrate	KAP/REWAB ingredients	KAP/REWAB ingredients	KAP/REWAB ingredients	KAP/REWAB ingredients	KAP/REWAB ingredients	KAP/REWAB ingredients
PFAS	Literature	Literature	Literature	Literature	Literature	Literature
Dioxins and dioxin-like PCBS	KAP ingredients	KAP ingredients	KAP ingredients	KAP ingredients	KAP ingredients	KAP ingredients
Non-dioxin-like PCBs	KAP ingredients	KAP ingredients	KAP ingredients	KAP ingredients	KAP ingredients	KAP ingredients

NA means not available
NR not relevant for the specific product group
WFSR Wageningen Food Safety Research
KAP Quality Program Agricultural Product; values for replacers were available
KAP ingredients; values for ingredients of replacers were available
REWAB Registratie opgaven van Drinkwaterbedrijven
Deoxynivalenol (DON) and metabolites (3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside)

Appendix 4 Data handling of data extracted from KAP and REWAB databases

The KAP extract contained more than 66,000 records. Prior to further data analysis, the data set was cleaned.

1) It was assumed that each concentration below the limit of quantification (LOQ) was equal to half the value of the LOQ (middle bound concentration; EFSA 2010b);
2) Concentrations of substances belonging to a group of substances and reported as the sum of those substances were removed from the dataset since these summed concentrations include the values below LOQ expressed as ‘0’ (lower bound substitution). Including these summed substances would have led to an underestimation of exposure. Instead, individual concentrations were summed according to the MB scenario;
3) The concentrations of substances reported with different units (for example mg/kg or µg/kg) were adjusted to one harmonised unit
4) Dioxins and non-dioxin like PCBs (six indicator PCBs) were reported in KAP as pg/kg and ng/kg fat, respectively. Concentrations presented as pg or ng per kg fat were recalculated to pg or ng per kg product using available information on fat content of the products. For this, the mean fat content of the product group was used (i.e. 4.4% for milk, 44% for cheese, 13.3% for hot meat, and 29% for cold meat).
5) Individual values of substances for which a summed concentration is relevant for risk assessment were summed according to the summation rules presented in Table 4.5.
6) Only substances possibly present in the major ingredients of dairy and meat replacers (see Table 4.2) were considered. All other substances were excluded.

After data cleaning, a final data set of more than 34,000 records were included.

The REWAB extract represents the statistical summary of the Dutch drinking water monitoring program and contained more than 4,366 records. Information was available for nitrate, cadmium, lead, total mercury (assumed to be in the inorganic form; EFSA 2012a) nickel and total arsenic (assumed to be in the inorganic form; EFSA 2024). The number of samples per sampling point in the water distribution network across the Netherlands ranged from 1 to 54 per substance. For each substance the weighted average medium bound concentration was calculated.

Appendix 5 Mean concentrations used for the prioritisation of substances in dairy and meat replacers

This Appendix shows the mean concentrations of the substances occurring in replacers, the data source, number of data and the percentage measurements above the LOQ for dairy replacers (Table A5.1) and meat replacers (Table A5.2). Middle bound concentrations are shown, which means that measurements below the LOQ were assumed to equal half the value of the LOQ.

https://www.rivm.nl/bibliotheek/rapporten/2025-0163-appendix-5.xlsx

Appendix 6 Concentrations used for the calculation of PFAS in dairy and meat replacers

Schepens et al. (2023) published the concentrations of PFAS, expressed as PFOA-equivalents in foods on the Dutch market and in drinking water made from ground water and from surface water. Table A6.1 presents the summed PFAS concentrations in food at the lower bound (LB), upper bound (UB) and the mean value of those as proxy for the middle bound scenario. These concentrations were used to calculate the PFAS content in dairy and meat replacers presented in Tables 4.6 and 4.10.

Table A6.1 Concentrations of per and polyfluoroalkyl substances (PFAS) used for comparing differences in PFAS concentrations between dairy and dairy replacers and meat and meat replacers

Food	**LB (pg PEQ/kg product)**	**UB (pg PEQ/kg product)**	**Mean of LB and UB (pg PEQ/kg product)**
Animal origin			
Meat			
Beef	40	189	115
Minced meat	20	173	97
Pâté	60	238	149
Pork	30	179	105
Pork liver-type sausages	64	221	143
Dairy			
Milk	19	72	46
Plant origin			
Cereals and cereal products			
Rice grain	4.3	83	44
Wheat flour	6.2	66	36
Vegetable fats and oils			
Olive oil	0	124	62
Sunflower oil	3.1	91	47
Legumes			
Beans	12	57	35
Peas	0.79	22	11
Drinking water			
Ground water	1.5	50	26
Surface water	9.2	27	18

Appendix 7 Total exposure grades assessed for dairy replacers

This Appendix shows the dietary exposure assessment of substances via milk (drink) replacers, yoghurt replacers and cheese replacers, using the concentrations listed in Appendix 5. Dietary exposure via dairy replacers was assessed using standard portions (mean and P95) listed in Table 3.1 for 1- to 3-year-olds and adults, respectively. Estimated dietary exposures to a substance were divided by the toxicological reference value (TRV) of the substance (see Table 4.11; section 4.5.1). Subsequently, exposure grades were assigned to the estimated dietary exposure according to the rules explained in section 4.5.1.

https://www.rivm.nl/bibliotheek/rapporten/2025-0163-appendix-7.xlsx

Appendix 8 Total exposure grades assessed for meat replacers

This Appendix shows the dietary exposure assessment of substances via meat replacers for dinner, pâté replacers and slices replacers, using the concentrations listed in Appendix 5. Dietary exposure via dairy replacers were assesses using standard portions (mean and P95) listed in Table 3.1 for 1- to 3-year-olds and adults, respectively. Estimated dietary exposures to a substance were divided by the toxicological reference value (TRV) of the substance (see Table 4.11; section 4.5.1). Subsequently, exposure grades were assigned to the estimated dietary exposure according to the rules explained in section 4.5.1.

https://www.rivm.nl/bibliotheek/rapporten/2025-0163-appendix-8.xlsx

Appendix 9 Most recent Dutch exposure estimates used in the prioritisation of substances in replacers of dairy and meat and the assignment of exposure grades for these exposure estimates

This Appendix shows the most recent Dutch mean and P95 exposure estimates. Sometimes mean exposure estimates were not available and then the P50 exposure estimates were used as a proxy. Sometimes, a mismatch occurred between the age groups included in our study and those reported in the most recent Dutch exposure assessment. In that case, the age groups most closely resembling the age groups in our study were selected. Finally, MB exposure estimates were not always available. The averaged value of the lower bound scenarios (values below the LOQ are zero) and upper bound scenario (values below the LOQ equals the value of the LOQ) was used as a proxy for the MB scenario.

https://www.rivm.nl/bibliotheek/rapporten/2025-0163-appendix-9.xlsx

Appendix 10 Expert judgment of the substances prioritised by ranking exposure grades

Section 4.6 summarizes the expert judgement for the substances selected in section 4.5. This Appendix describes the expert judgment step in more detail for each of the substances Expert judgment included the suitability of the concentration data for substances in dairy and meat replacers. If insensitive analytical methods (i.e. methods with a low LOQ) were used, results from studies using more sensitive studies published in literature (if available) were also shown.

Alternaria toxins

The genotoxic *Alternaria* toxins AOH and AME were measured in 38 milk (drink) replacers and in ten cheese replacers. All values were below the LOQs of 10 and 3 µg/kg for AOH for respectively milk (drink) replacers and cheese replacers and of 100 and 3 µg/kg for AME for respectively milk (drink) replacers and cheese replacers. It should be noted that AOH and AME were analysed with a multi method that analyses multiple mycotoxins within a single run. Such an analytical method is highly valuable for enforcement purposes since the LOQ is set in such a way it can be used to detect whether the concentrations of substances remain below regulatory maximum levels. However, this method is less suitable for risk assessment purposes due to these relatively high LOQ values. In literature, results obtained with more sensitive analytical methods were found. Using a method with a LOQ of 3- 8 µg/L for both AOH and AME, AOH was quantifiable in 12% of the oat-based milk (drink) replacers (n=17) but not in milk (drink) replacers based on soy, almond or rice (n=18, 11, and 10, respectively) and AME was not quantifiable in any of these replacers in a Spanish study (Juan et al., 2022). In another Spanish study using a sensitive method with a LOQ 0.02 µg/L for, AME levels were quantifiable in 100% of the almond-based milk (drink) replacers (n=7), 87% of the oat-based (n=16), 100% of the rice-based (n=6) and 44% of the soy-based milk (drink) replacers (n=9) (Rodrigues-Canas et al., 2024). AOH levels were not reported.

No Dutch concentrations for *Alternaria* toxins in meat replacers were available. However, analytical data on *Alternaria* toxins in wheat were available, and these were used to calculate, based on the standard recipes listed in Table 4.1, the concentrations in wheat-based meat replacers . It should be noted that all 29 measurements for AOH and AME in wheat were below the LOQ. The calculated MB concentration in wheat-based meat replacers for dinner were 1.8 µg/kg for AOH and 8 µg/kg for AME. Data on AOH and AME in meat replacers was available from literature. In a study were, 19 soy-based meat replacers analysed with a method with LOQs of 0.5 µg/L for AOH and 0.12 µg/L for AME. AOH was detected in one (5%) sample and AME in 18 (95%) samples (Rodriguez-Carrasco et al. 2019). In an Italian study, AOH was detected in 3 out of 13 (23%) meat replacers (one pea-based, one chicken-pea/wheat gluten-based and one soy/wheat-based) and AME was detected in 6 out of 13 (46%) meat replacers (2 lupin/gluten-based, 2 soy-based, 1 chicken pea/gluten based, and 1 pea-based. The LOQs were 2.9 µg/kg for AOH and 0.09 µg/kg for AME (Mihalache et al., 2024).

These studies indicate that AOH and AME may occur at quantifiable levels in milk (drink) replacers and meat replacers if more sensitive methods are used. AOH and AME were therefore not selected for the exposure assessment. The use of sensitive methods is needed for a dietary exposure assessment of these mycotoxins.

Aflatoxins

Aflatoxins were analysed in 140 meat replacers based on mycoprotein, soy or unspecified in 2021, in 4 almond- and 5 oat-based milk replacers in 2024 and in one almond- and one cashew nut-based cheese in 2025 (Annex 2). All measurements were below the LOQ of 1 µg/kg for each aflatoxin in milk and meat replacers and 0.05 µg/kg in cheese replacers. Like *Alternaria* toxins, aflatoxins were analysed with a multi method.

Using a more sensitive method with an LOQ of 0.001 µg/l, aflatoxins were quantifiable in two out of three oat-based milk drinks and none of the three soy-based milk drinks (Mira-Abella et al., 2017). In another study using a sensitive method with LOQs varying from 0.002 µg/L for AFG2 to 0.013 for AFG1, 28% of the almond-based drinks (n=7), 0% of the oat-based (n=16), 33% of the rice-based (n=6) and 11% of the soy-based drinks (n=9) had quantifiable values for aflatoxins (Rodriguez- Canas et al., 2024). In a study with LOQs varying between 0.4 and 1.1 µg/L (depending on the matrix), aflatoxins were quantifiable in oat-based (n=11) and almond-based drinks (n=17), but not in soy-based (n=18) or rice-based drinks (n=11; Juan et al., 2022). The percentage of drinks above the LOQ for oat- and almond-based drinks were not provided by Juan et al. (2022).

Studies with more sensitive methods have also been published for meat replacers. In one study with an LOQ of 0.04 µg/L, AFB1 was only quantifiable in one out of 19 soy-based burgers whereas all AFB2, AFG1 and AFG2 measurements were below the LOQ (Rodriguez-Carrasco et al., 2019). However, in an Italian study analysing 13 meat replacers and using a less sensitive analytical method (LOQs varied from 0.84 µg/kg for AFB2 to 2.5 µg/kg for AFG2), AFB1 was detected in three samples (23%), AFB2 in none, AFG1 in one (8%) and AFG2 in three samples 23%. Aflatoxins were mostly detected in soy-based products (n=3), followed by lupin-wheat products (n=2) and chickpea-wheat products (n= 1) (Mihalache et al.,2023).

These literature studies indicate that quantifiable, though highly variable, aflatoxin concentrations may occur in dairy and meat replacers when more sensitive analytical methods are used. Therefore, aflatoxin concentrations in dairy and meat replacers measured with a sensitive analytical method are needed for a dietary exposure assessment.

T-2 and HT-2 toxins

The mycotoxins T-2 and HT-2 were not quantifiable in oat-based milk replacers and yoghurt replacers . Like aflatoxins, T-2 and HT-2 were detected with a less sensitive multi method with an LOQ of 10 µg/kg.

Using a more sensitive method with an LOQ of 0.5 µg/kg, T-2 toxin was detected in all oat-based milk replacers (n=3) by Miro-Albella et al. (2017). In another study, T-2 and HT-2 toxin were detected in respectively 40% and 33% of the 16 oat-based milk replacers when a more sensitive method with LOQs of 0.12 µg/L for T-2 toxin and 0.47 µg/L for HT-2 toxin was used (Rodrigues-Canas et al., 2024). For an accurate exposure assessment, concentrations measured with a more sensitive analytical methods are needed. Therefore, T-2 and HT-2 toxins in oat-based milk replacers and yoghurt replacers were not selected for the exposure assessment.

Deoxynivalenol (DON) and metabolites

DON and metabolites (3-acetyl-DON, 15-acetyl-DON and DON-3-glucoside) in oat-based milk replacers were also analysed with the multi method with an LOQ of 80 µg/kg and none of the values were above the LOQ. In other studies in which DON was measured in oat-based milk replacers, it was not detected (n=3, LOQ of 15 µg/L, Miro-Albella et al., 2017; n=16, LOQs of 0.37, 8.06 and 10.68 µg/L for respectively 3-Ac-DON, 15-Ac-DON and DON, Rodrigues-Canas et al., 2024) or present in 38% of the samples (n=8, LOQ of 53.6 µg/L, Hamed et al., 2017). As for the other mycotoxins, a more sensitive analytical method is needed, therefore, DON and metabolites were not selected for the exposure assessments .

Acrylamide

Acrylamide is a process contaminant that can be formed during heat treatment (above 120°C) out of the amino acid arginine and reducing sugars, particularly in foods low in moisture and high in carbohydrates (EFSA, 2017). Therefore, the generation of acrylamide is not expected during pasteurisation processes of unsweetened milk drink or yoghurt replacers, because of their high water content. However, acrylamide may be generated during heat-treatment of the major ingredients. In our study, acrylamide was detected at quantifiable concentrations in one almond-based milk drink replacer based on roasted almonds and in one milk replacer based on oat-flakes. Oat flakes are produced in a process that includes steaming, dry heating and rolling. Dry heating enhances Maillard reactions in oat flakes and thus acrylamide formation (Decker et al., 2014). Roasted nuts and breakfast cereals like rolled oats are known to contain acrylamide (EFSA, 2017). Acrylamide in almond and oat-based milk replacers has also been reported by Pucci et al. (2024).Therefore, the concentrations for acrylamide in dairy replacers based on almond and oat are considered suitable for dietary exposure assessment.

Acrylamide can also be generated during heating of the breaded layer of meat replacers and meat products during home preparation of the foods. In our project, acrylamide levels in fried breaded and unbreaded meat replacers were used (WFSR 2021). Currently, acrylamide is analysed in cooked breaded meat products in the CoVo project (CoVo) and risk assessment will be performed in 2026. Therefore, a comparison of breaded meat replacers with breaded meat products and an intake assessment of acrylamide can be performed in the future.

PAHs

Insufficient recent Dutch data on PAH concentrations in home-prepared meat products were available for the comparison of the concentration of PAHs in meat compared with replacers. The most recent assessment of PAHs was performed in 2008 by EFSA, and other Dutch assessments have been performed in the nineties and eighties of the last century (Vaessen et al., 1988; de Vos et al., 1990). Dietary exposure to PAHs via heated meat may have changed because of increasing awareness of the possible health effects of burned meat. Therefore, baseline dietary exposure to PAHs cannot be performed. PAHs can also occur in roasted nuts and grains (EFSA 2008). Since some milk replacers contain roasted almonds or dry-heated oat, PAHs may be present in those milk replacers but no Dutch concentration data were available for PAHs in milk replacers. In conclusion, more data is needed before being able to assess the dietary exposure. Further, EFSA also derived a $BMDL_{10}$ for eight PAHs (benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, chrysene, dibenz[a,h] anthracene and indeno[1,2,3-cd]pyrene). For risk assessment purposes therefore, all these eight PAHs are preferably measured.

MOAH

MOAH can contaminate food via several routes, such as environmental contamination, lubricants for machinery used during harvesting and food production, processing aids like release agents or dust binders, food or feed additives and food contact materials (EFSA 2023). Vegetable oils and fats are a well-known source of MOAH, therefore, dairy replacers and meat replacers containing high amounts of vegetable oils or fats, such as cheese replacers based on coconut oil and meat replacers. In our study, MOAH in meat replacers was ranked as priority substance. Analytical values were available for meat replacers for dinner (36% of analytical values above LOQ), pâté (20% above the LOQ) and slices (24% above the LOQ). Therefore, the concentration data for MOAH in meat replacers were considered as suitable for dietary exposure assessment

GEs

GEs are process contaminants predominantly found in vegetable oils generated during the deodorisation step of edible oil refining which takes place at high temperatures. GEs was prioritised in meat replacers for dinner, pâté replacers and slices. Regarding meat replacers for dinner, the substance was analysed in prepared products, fried in vegetable oil. Part of the GEs content was explained by absorption of the GEs-containing frying oil (WFSR 2024). For pâté replacers and slices, the presence of GEs can be likely explained by the high vegetable fat content of these products (20 and 24% respectively). Since all analysed products (replacers for dinner, pâté and slices) were above the LOQ, the concentration data for meat replacers are considered as suitable for exposure assessment. GEs are therefore prioritised for dietary exposure assessment.

Erucic acid

Erucic acid is a contaminant naturally present in the seeds of plants from the Brassica family (such as rape seed oil, EFSA 2015). The substance is prioritised for meat replacer for dinner and pâté, because rapeseed oil is a frequently used ingredient in these products. Several meat replacers for dinner, pâté replacer and slices contained rapeseed oil according to LEDA (extract of 2023). In our study, calculated values of erucic acid were used for the prioritisation, with only 7% of analysed values for edible oils above the LOQ. Therefore, these concentration data are not useful for dietary exposure assessment and measurements of erucic acid in rapeseed containing meat replacers bare needed.

iAs

Inorganic arsenic was prioritised for refined exposure assessments based on its ranking of milk (drink) replacers (coconut, pea and rice-based) cheese replacers (almond-based), meat replacers for dinner (pea, soy and wheat) and pâté replacers (wheat-based). iAs was analysed in milk (drink) replacers by WFSR in 2024, and all measurements in replacers based of pea (n=2) and rice (n=4) had values above the LOQ. In addition, 40% of analytical values in coconut-based milk (drink) replacers were above the LOQ. Rice is a well-known source of iAs (EFSA 2021) and indeed iAs was found in rice-based milk (drink) replacers. Other studies also found total As (tAs) in rice-based milk replacers (Redan et al 2023, Astolfi et al 2020, EFSA 2021). Also tAs was found in coconut-based milk replacers (Redan et al 2023, Astolfi et al 2020) although tAs was not found in coconut (EFSA 2021). Contrary to our findings, Redan et al. (2023) did not find tAs in pea-based milk (drink) replacers and a large number of pea samples in the occurrence data used by EFSA in 2021 was below the LOQ. Contribution of other ingredients, such as water, the major ingredient of milk (drink) replacers cannot be excluded.

Regarding almond-based cheese replacers and wheat-based pâté replacers, calculated values were used for the prioritisation. For almond-based cheeses all the ingredients had values above the LOQ, whereas for wheat-based pâté replacers, none of the ingredients had a value above the LOQ.

A large part of the meat replacers for dinner also had values above the LOQ (50% for pea-based meat replacers and 74% for wheat and soy, respectively). In the occurrence data used by EFSA in 2021, approximately 25% of soy-based meat replacers contained quantifiable tAs levels, which was comparable to soy bean and soy flour.

In conclusion, the concentration data for iAs in milk (drink) replacers and meat replacers for dinner are suitable for dietary exposure assessment.

Lead

Lead was prioritised for refined exposure assessments, based on its ranking of milk (drink) replacers (almond, coconut, oat, pea, rice and soy), yoghurt replacers (almond, coconut, oat and soy) meat replacers for dinner (pea, wheat and soy-based) and pea-based slices. None of the milk (drink) replacers has a value above the LOQ. Other studies showed that some measurements in milk (drink) replacers had lead values above the LOQ (almond, cashew and coconut-based milk (drink) replacers; Redan et al, 2023). In literature, MB mean values in milk replacers were comparable with the one used in our study (Redan et al 2023, Astolfi et al 2020). Values for cheese replacers were above the LOQ. Concentration data for lead in milk (drink) replacers were deemed suitable for dietary exposure assessment.

Regarding meat replacers, 33% of soy-based meat replacers for dinner had values above the LOQ, for pea-based and wheat-based replacers this was only 12%. MB mean values in meat replacers in our study was comparable to those obtained by WFSR/NVWA in 2020, but slightly lower than those observed in literature, in which the lead concentration varies between 0.01 and 0.05 mg/kg for Spanish meat replacers for dinner (Padron et al 2020, Paz et al 2021). Therefore, concentration data of lead in meat replacers were judged suitable for dietary exposure assessment.

Cadmium

Based on the ranking of milk (drink) replacers (oat, rice and soy), yoghurt replacers (soy) and meat replacers for dinner (pea, wheat and soy-based) cadmium was prioritised for refined exposure assessment. All measurements of the dairy replacers were above the LOQ. The cadmium concentrations were comparable to those reported in literature (Redan et al 2023; Astolfi et al 2020). Therefore, concentration data of cadmium in dairy replacers we judged suitable for dairy exposure assessment

For the meat substitution scenario, all measurement of meat replacers for dinner were above the LOQ, but only 10% of the values of pâté replacers and slices were above the LOQ. For dinner, MB mean concentrations were comparable with those obtained by NVWA/WFSR in 2020 and slightly higher than those found in Spanish meat replacers (0.01 mg/kg Padron et al 2020; Paz et al 2021). Therefore, concentration data of cadmium in meat replacers were deemed relevant for dietary exposure assessment.

Appendix 11 Concentrations used for the dietary exposure assessments of cadmium and lead

This Appendix shows the mean concentrations used to assess the dietary exposure to cadmium and lead at the middle bound scenario, in which analytical measurement below the LOQ were assumed to be equal to half the value of the LOQ. Concentrations were linked to consumption data via the coding system of the Dutch national food composition database NEVO.

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