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Risk assessment of PFAS through consumption of home-produced eggs in the Netherlands

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Colophon

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Synopsis

Risk assessment of PFAS through consumption of home-produced eggs in the Netherlands

A new study has shown that home-produced eggs (i.e. eggs from privately owned chickens) throughout the Netherlands may contain significant amounts of PFAS. As a consequence, people who eat these eggs may ingest a great deal of these substances. As the amount of PFAS in an egg cannot be deduced from a visual inspection, RIVM advises people throughout the Netherlands not to eat home-produced eggs. It is as yet unclear how these chemicals end up in home-produced eggs and if anything can be done about it. RIVM is currently investigating this matter.

Commercially produced eggs bought in shops or on markets are safe to eat, as they contain far lower amounts of PFAS. Home-produced eggs are eggs laid by chickens that people keep as a hobby, for example in their own back garden or kitchen garden or in a field, therapeutic farm or petting zoo.

This RIVM risk assessment was prompted by the discovery in 2024 of significant amounts of PFAS in eggs laid by privately owned chickens in the surroundings of the Chemours chemical plant in the Dutch province of South Holland. The types of PFAS found in these eggs differed from the ones used at the plant. This raised questions about the situation in the rest of the country.

RIVM calculated the amounts of PFAS people could potentially ingest by eating home-produced eggs from 60 locations spread out over the whole of the Netherlands. It then compared these amounts with the health-based guidance value for PFAS. If people ingest more PFAS than this health-based guidance value over a longer period of time, it can be harmful to their health.

At 31 locations, it was found that people even ingested more PFAS than the health-based guidance value if they only ate one egg or less per week. At 10 locations, people could eat at most one egg per week without exceeding the guidance value. At five locations, this was true for at most two eggs per week, at three locations for at most three and at two locations for at most four. At nine locations, people could eat more than four eggs per week without exceeding the guidance value.

The exposure to PFAS through food and drinking water is already high. The amounts that people ingest by eating home-produced eggs is added to this. Consequently, RIVM advises against eating products containing significant amounts of PFAS, including home-produced eggs.

Keywords: PFAS, home-produced eggs, exposure, risk assessment

Publiekssamenvatting

Risicobeoordeling van PFAS via het eten van particuliere eieren in Nederland

In het hele land kan er veel PFAS in particuliere eieren zitten, zo blijkt uit nieuw onderzoek. Hierdoor kunnen mensen veel PFAS binnenkrijgen als zij deze eieren eten. Omdat aan een ei niet te zien is hoeveel PFAS erin zit, adviseert het RIVM om in heel Nederland geen particuliere eieren te eten. Het is nog niet duidelijk hoe PFAS in deze eieren komt en of er iets aan kan worden gedaan. Dat onderzoekt het RIVM nu.

Commerciële eieren uit een winkel of van de markt kunnen wel worden gegeten, want daar zit veel minder PFAS in. Particuliere eieren komen van kippen die als hobby worden gehouden, bijvoorbeeld in achtertuinen, moestuinen, dierenweitjes en zorg- en kinderboerderijen.

Het RIVM deed de risicobeoordeling omdat in 2024 hoge hoeveelheden PFAS in particuliere eieren rond het bedrijf Chemours in Zuid-Holland waren gevonden. De typen PFAS in deze eieren waren anders dan het bedrijf gebruikte. Zo ontstond de vraag hoe het in de rest van het land zit.

Het RIVM berekende hoeveel PFAS mensen kunnen binnenkrijgen via particuliere eieren van 60 locaties, verspreid over heel Nederland. Deze hoeveelheden zijn vergeleken met de gezondheidskundige grenswaarde. Als mensen een langere tijd meer PFAS binnenkrijgen dan deze grenswaarde, kan dat schadelijk zijn voor hun gezondheid.

Via de eieren van 31 locaties krijgen mensen al meer PFAS binnen dan de gezondheidskundige grenswaarde als zij 1 ei of minder per week eten. Op 10 locaties kunnen ze maximaal 1 ei per week eten zonder over deze grenswaarde heen te gaan. Op 5 locaties is dit bij maximaal 2 eieren het geval, op 3 locaties bij maximaal 3 en op 2 locaties bij maximaal 4 eieren. Op 9 locaties kunnen mensen elke week meer dan 4 eieren eten zonder de grenswaarde te overschrijden.

Mensen krijgen al veel PFAS binnen via voedingsmiddelen en drinkwater. De hoeveelheid die mensen via particuliere eieren binnenkrijgen, komt daar bovenop. Het is daarom af te raden om producten te eten waar veel PFAS in zit, zoals particuliere eieren.

Kernwoorden: PFAS, particuliere eieren, blootstelling, risicobeoordeling

Contents

1 Introduction

In 2024, the National Institute for Public Health and the Environment (RIVM) assessed the risk of exposure to per- and polyfluoroalkyl substances (PFAS; see Box 1) through the consumption of home-produced eggs from 31 locations, 28 of which were situated in the vicinity of Chemours (Boon et al., 2024). Chemours is a chemical plant in Dordrecht that uses PFAS in its production processes, specifically perfluorooctanoic acid (PFOA) until 2012 and GenX since then.[1]

Box 1: *PFAS*

Per- and polyfluoroalkyl substances (PFAS) is a large group of synthetic chemicals that have been widely used in industrial applications and consumer products. Known for their unique chemical properties, including resistance to heat, water, and oil, PFAS have been utilised in a variety of products, such as non-stick cookware, water-repellent clothing, stain-resistant fabrics, and firefighting foams. Despite their usefulness, PFAS have raised significant environmental and public health concerns, due to their persistence in the environment and their potential to bioaccumulate in living organisms. Exposure to PFAS can occur through various pathways, food and drinking water being the most common sources of exposure in the general population.

High PFAS concentrations were detected in these eggs. The consumption of eggs from 22 locations would result in an exceedance of the health-based guidance value (HBGV) of PFAS (see Box 2 on the next page), even at one egg per week. Therefore, it was advised not to consume home-produced eggs from this region. Interestingly, the PFAS found in the eggs was mainly perfluorooctane sulfonic acid (PFOS), which has, to our knowledge, not been emitted by Chemours.

In 2024, the Office of Risk Assessment and Research (BuRO) of the Netherlands Food and Consumer Product Safety Authority (NVWA) published a risk assessment of PFAS in home-produced eggs in the Netherlands (BuRO, 2024). This risk assessment was based on PFAS measurements by Zafeiraki et al. (2016) in home-produced eggs collected in 2013-2014. BuRO showed that home-produced eggs from other regions in the Netherlands could also contain high PFAS concentrations and could pose a health risk when consumed. No connection could be made with any known source of contamination.

As the findings of BuRO were based on home-produced eggs collected more than 10 years ago, the Dutch Ministry of Health, Welfare and Sport has asked RIVM to investigate the current concentrations of PFAS in home-produced eggs in the Netherlands and to perform a risk assessment of PFAS exposure through their consumption.

[1] Strictly speaking, GenX is not a substance, but a technology used in the production of fluorinated polymers. Two fluorinated substances are used in this process. The effects of these two substances in the body are caused by the negatively charged ion (anion) of the ammonium salt (HFPO-DA). This anion is referred to as GenX. See Boon et al. (2019) for a description of GenX.

Box 2: *Health-based guidance value of PFAS*

The European Food Safety Authority (EFSA) has derived a health-based guidance value (HBGV) of PFAS (EFSA, 2020). An HBGV indicates the maximum amount of a substance that a person can ingest without adverse effects due to that substance. This value is used in risk assessment to determine whether the exposure to a substance may pose a health risk. The HBGV of PFAS is set at 4.4 nanograms per kilogram body weight per week. This value is based on adverse effects of PFAS on the immune system, which can occur after exposure to PFAS over a longer period of time. These effects were considered the most critical.

The HBGV is based on the sum of four PFAS, the so-called EFSA-4, consisting of perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), and perfluorohexane sulfonic acid (PFHxS) (EFSA, 2020).

RIVM uses the HBGV together with the relative potency factor (RPF) approach for the risk assessment of PFAS (see section 3.2) (RIVM, 2021).

Furthermore, the ministry requested an investigation into the source or sources of PFAS contamination of these eggs could be, and whether these concentrations can be reduced.

In this report, we assess the risk of PFAS exposure through the consumption of home-produced eggs in the Netherlands. We will provide insight into the amount of PFAS a person can ingest when consuming home-produced eggs. This amount is compared to the HBGV of PFAS. The sum of the PFAS concentrations analysed in the eggs is used for the risk assessment. These summed concentrations are calculated using the relative potency factor (RPF) approach (RIVM, 2021).

2 Collection and analysis of the eggs

2.1 Selection of participants and collection of the eggs

This study focused on home-produced eggs from chicken owners living in the Netherlands, who keep chickens as a hobby. To recruit participants, a Formdesk form was shared via social media channels of RIVM, inviting people to apply for participation. In this form, questions were asked about the number of chickens kept, the place of residence and province, the housing of the chickens (coop, free-range and/or vegetation), and whether eggs had been measured for PFAS before. The registration was closed after only 2.5 days, due to the high number of applications.

Out of the 2570 applications, 60 participants were selected. Since this study focused on people who keep chickens as a hobby, only those who owned fewer than 10 chickens were selected, leaving 2150 applicants. These participants were divided based on the method of housing. From each group participants were selected, paying extra attention to a good distribution of locations across the twelve provinces of the Netherlands (at least three locations per province). Selected participants were asked to share their address. Participants who did not respond, no longer wanted to participate, or were unable to send their eggs before the deadline were replaced. Participants were replaced as much as possible by those with the same housing method and from the same province. The selected locations are shown in Figure 1.

Figure 1 The sixty selected locations.

The blue dots represent the locations from which home-produced eggs were collected.

To collect home-produced eggs from the selected participants, cardboard shipping boxes (25 x 25 x 11 cm) containing foam rubber with holes for eggs were sent to the participants. Participants were asked to send 5-10 eggs, collected in August 2024, to Wageningen Food Safety Research (WFSR) at Wageningen University & Research (WUR). The WFSR laboratory analysed the eggs for PFAS (see section 2.2). Three participants sent fewer than five eggs.

Per participant, one composite sample of all collected eggs was analysed for PFAS. In the 2024 risk assessment of home-produced eggs in the region around Chemours, both a composite sample and a sample of a single egg were analysed for most locations. Since the PFAS concentrations in the two samples turned out to be similar for each location (Boon et al., 2024), the current study only analysed one composite sample per participant.

The eggs were obtained from 60 participants, resulting in 60 composite samples. Each participant represents a location in the Netherlands. In the rest of this report, we will refer to the locations instead of participants as the locations are the relevant entity for our study.

2.2 Analysis of PFAS

The analysis of PFAS was performed as described in Boon et al. (2024). WFSR analysed the composite samples for 18 PFAS (see Table 1 on the next page). These 18 PFAS were chosen because they are included in the analytical method applied by WFSR. The eggs were analysed raw. Prior to the analysis, eggshells were removed, and the eggs (yolk and egg white) were pooled and homogenised.

The 18 PFAS were analysed according to WFSR's internal Standard Operating Procedure (SOP) A1114. One gram per sample was weighed. Following extraction with acetonitrile and purification via Solid Phase Extraction, the sample extracts were analysed using liquid chromatography (LC) coupled with tandem mass spectrometry (MS/MS).[2] The analytical LC column was a Phenomenex Luna Omega 1.6 µm PS C18 100 Å (100 x 2.1 mm) and a Phenomenex Gemini 3 µm C18 110 Å (50 x 3 mm) isolator column. The solvents used to pass the sample extracts through the column were mobile phases A and B (A: 20 mM ammonium acetate in water; B: 100 percent acetonitrile; flow rate 0.8 ml/min).

The MS operated in multiple reaction monitoring, where each PFAS is monitored on the basis of two ion transitions (with the exception of perfluorobutanoic acid (PFBA) and perfluorpentanoic acid (PFPeA), because only one ion transition is available for these PFAS). The amount of each PFAS was quantified using calibration curves, prepared in the presence of the matrix.[3] If possible, the calibration curves were made with isotope-labelled internal standards for the linear isomers of PFAS. Since most PFAS in food are present as linear isomers, the concentrations of each isomer are reported.

[2] LC-MS/MS, LC: Shimazdu ExionLC AD; MS: Sciex 7500.
[3] The matrix includes all other substances in a sample besides the substance to be analysed.

Table 1 The 18 PFAS included in the analysis of the samples.

Sulfonic acids

PFAS	**PFAS abbreviation**
Perfluorobutane sulfonate	PFBS
Perfluorohexane sulfonate	PFHxS
Perfluoroheptane sulfonate	PFHpS
Perfluorooctane sulfonic acid	PFOS
Perfluorodecane sulfonate	PFDS

Carboxylic acids

PFAS	**PFAS abbreviation**
Perfluorobutanoic acid	PFBA
Perfluoropentanoic acid	PFPeA
Perfluorohexanoic acid	PFHxA
Perfluoroheptanoic acid	PFHpA
Perfluorooctanoic acid	PFOA
Perfluorononanoic acid	PFNA
Perfluorodecanoic acid	PFDA
Perfluoroundecanoic acid	PFUnDA
Perfluorododecanoic acid	PFDoDA
Perfluorotridecanoic acid	PFTrDA
Perfluorotetradecanoic acid	PFTeDA

Ether carboxylic acids

PFAS	**PFAS abbreviation**
Hexafluoropropylene oxide dimer acid	HFPO-DA (GenX)
3H-perfluoro-3-[(3-methoxy-propoxy)propionic acid]	ADONA

PFAS: per- and polyfluoroalkyl substances

However, perfluorohexane sulfonic acid (PFHxS), PFOA, and PFOS can also be present in food as branched isomers. No branched isomers were observed for PFHxS in the samples. Branched isomers of PFOA were present, but the concentrations were too low to distinguish them from the background signal. For PFOS, branched isomers were quantified using the calibration curves for the linear isomers as described in the guidance document on the analysis of PFAS.[4] While this may result in a small inaccuracy in the reported concentrations of PFOS (linear and branched), it is expected to be minimal.

The analytical method has two analytical limits:

- Limit of Detection (LOD): the lowest concentration of a PFAS that can be detected but not quantified.
- Limit of Quantification (LOQ): the lowest concentration of a PFAS that can be quantified with established precision and at which the identity of the PFAS can be confirmed.

These limits varied per PFAS, because these substances do not have the same chemical properties, which affects their behaviour in the LC-

[4] EURL for halogenated POPs in Feed and Food (2024): Guidance Document on Analytical Parameters for the Determination of Per- and Polyfluoroalkyl Substances (PFAS) in Food and Feed, version 2.0 of 10 September 2024. https://eurl-pops.eu/working-groups#_pfas

MS/MS.[5] Furthermore, due to analytical reasons, the LOD and LOQ for a PFAS may not always be the same in a run. Therefore, the LOD and LOQ for a PFAS may differ between samples.

The LOD is always lower than the LOQ. The LOD ranged from 0.005 to 0.025 nanogram (ng) per gram, and the LOQ from 0.01 to 0.10 ng per gram.

[5] Long-chain PFAS (such as PFOA and PFOS) tend to adhere to the LC column more than short-chain PFAS (such as PFBA and PFBS).

3 Calculation of PFAS exposure and maximum number of eggs

Calculations of PFAS exposure through the consumption of the eggs from the 60 locations were performed as described in Boon et al. (2024). By using the analysed PFAS concentrations in the samples, the exposure to PFAS per location was calculated for the consumption frequencies of one, two, four, or seven eggs per week, or one egg per month. Additionally, the maximum number of eggs that can be consumed without exceeding the HBGV of PFAS (see Box 2 in chapter 1) was calculated for each location. For both calculations, the concentrations of PFAS in the samples were summed using the RPF approach to obtain a summed PFAS concentration per sample. PFAS exposure through other food and drinking water was not included in these calculations but will be addressed in the risk assessment (see chapter 5).

The following sections describe how the calculations were performed, either in Excel or in R (packages xlsx, writexl, janitor, tidyr, dplyr, ggplot2, pheatmap, and palletteer).

3.1 Concentrations of PFAS

Appendix A provides an overview of the PFAS concentrations in the samples. The concentrations were reported in four ways:

1. < LOD (limit of detection): the PFAS could not be detected; the concentration of the respective PFAS is between 0 ng per gram and the LOD.
2. < LOQ (limit of quantification): the PFAS was detected, but the exact concentration could not be quantified, and its identity could not be confirmed with 100 percent certainty; the concentration of the respective PFAS is between 0 ng per gram and the LOQ.
3. c (numerical concentration): the PFAS was detected and the concentration could be accurately quantified; the concentration of the respective PFAS is equal to 'c'.
4. n.d. (not determined): the PFAS could not be determined due to a high background signal (this is different from a PFAS that could not be detected and is reported as '< LOD').

The PFAS concentrations reported as 'c' were included in the exposure calculations as such. The PFAS that could not be determined (n.d.) in some or any samples were not included in the calculations. For concentrations reported as '< LOD' or '< LOQ', it is unknown whether the respective PFAS are present in the sample. These PFAS may not be present (0 ng per gram) or they may be present at a concentration ranging between 0 ng per gram and the respective analytical limit. In the calculations, it was assumed that these PFAS were not present in the respective sample. Table 2 (see the next page) shows the concentrations assigned to a PFAS per reported concentration.[6]

[6] Please note that the approach of assigning concentrations to samples with a reported concentration '< LOD' and '< LOQ' is equal to the so-called 'lower bound scenario'.

Table 2 PFAS concentrations allocated to the reported concentrations in the calculations.

Reported concentration	Allocated concentration in the calculations
< LOD	0
< LOQ	0
c	c
n.d.	Not included

c: numerical concentration; LOD: limit of detection; LOQ: limit of quantification; n.d.: not determined; PFAS: per- and polyfluoroalkyl substances

3.2 Calculation of the summed concentrations using relative potency factors

The exposure to PFAS through the consumption of home-produced eggs and the maximum number of eggs that can be consumed without exceeding the HBGV were calculated using the summed concentrations of PFAS in the samples. To calculate the summed concentrations, the RPF approach was used (RIVM, 2021). With this approach, individual PFAS concentrations are multiplied by their RPFs, and then summed. The RPFs express the ability of each PFAS to cause an effect on the immune system relative to that of the 'index' PFAS PFOA (see Box 2 in chapter 1). Thus, the RPF of PFOA is 1. PFAS with a greater ability to cause the effect than PFOA have an RPF greater than 1, and PFAS with a lower ability have an RPF less than 1. Table 3 (see the next page) lists the RPFs used in the calculations (Bil et al., 2021). Using these RPFs, individual PFAS concentrations in a sample are expressed as PFOA equivalents (PEQ) and consequently summed into one summed concentration of PFAS expressed as PEQ per sample. Box 3 provides an example of such a calculation.

Box 3: *Example calculation of a summed PFAS concentration using RPFs*

A fictitious sample contains PFOA, PFHxA, and PFOS at 0.05, 1.0, and 0.01 ng per gram, respectively. The other PFAS are analysed at a concentration below the LOD or below the LOQ. PFOA is the reference compound. The RPFs are 1 for PFOA, 0.01 for PFHxA, and 2 for PFOS.

The summed concentration in PFOA equivalents (PEQ) for this fictitious sample is: (0.05 x 1) + (1.0 x 0.01) + (0.01 x 2) = 0.08 ng PEQ per gram. The PFAS with an analysed concentration below the LOD or below the LOQ are assumed not to be present in the sample (0 ng per gram).

To calculate the summed concentrations of PFAS, expressed as PEQ, in the samples of the current study, the reported concentrations for each individual PFAS were first imputed as described in Table 2 (see section 3.1). Subsequently, the individual PFAS concentrations were multiplied by their respective RPFs (see Table 3), and the concentrations expressed as PEQ were summed to obtain the summed PFAS concentrations for each sample.

Table 3 RPFs for the 18 PFAS analysed in the samples.

Sulphuric acids

PFAS[a]	RPF[b]
PFBS	0.001
PFHxS[c]	0.6
PFHpS	2
PFOS[c]	2
PFDS	2

Carbonic acids

PFAS[a]	RPF[b]
PFBA	0.05
PFPeA	0.05
PFHxA	0.01
PFHpA	1
PFOA[c]	1
PFNA[c]	10
PFDA	10
PFUnDA	4
PFDoDA	3
PFTrDA	3
PFTeDA	0.3

Ether carboxylic acids

PFAS[a]	RPF[b]
ADONA	0.03
HFPO-DA (GenX)	0.06

PFAS: per- and polyfluoroalkyl substances; RPF: relative potency factor
[a] The names of the PFAS are listed in Table 1 in section 2.2.
[b] Relative potency factors (RPFs) as derived by Bil et al. (2021). The RPFs for PFDA, PFHpA, PFHpS, PFPeA, and PFTrDA were derived as a range by Bil et al. (2021). In these cases, the highest RPF of the range was used to calculate the summed concentrations as recommended by RIVM (2021).
[c] PFAS belonging to the EFSA-4. These are the PFAS on which the health-based guidance value of PFAS is based (see Box 2 in chapter 1).

3.3 Calculation of PFAS exposure for five consumption frequencies

Using the location-specific summed PFAS concentrations, the exposure to PFAS was calculated for the consumption frequencies of one, two, four, or seven eggs per week. These frequencies were chosen as possible consumption frequencies of eggs. The Netherlands Nutrition Centre indicates that eating two to three eggs per week fits within a healthy diet and that vegetarians can eat three to four eggs per week.[7] Additionally, for the purpose of comparison, the exposure to PFAS was calculated for a consumption frequency of one egg per month. The latter exposure is only reported in section 4.2 and is not discussed further.

For the calculation, it was assumed that an egg weighs 50 grams.[8] The calculated exposure to PFAS was expressed per kilogram (kg) body weight by dividing it by an average body weight of 73 kg (Boon et al., 2024). The exposure can thus be compared to the HBGV of PFAS of

[7] https://www.voedingscentrum.nl/nl/service/vraag-en-antwoord/gezonde-voeding-en-voedingsstoffen/hoeveel-eieren-mag-ik-per-week-eten-.aspx#:~:text=De%20hoeveelheid%20eieren%20die%20wij,En%20hoeveel%3F
[8] This weight corresponds to the average weight of an egg of weight class M. An egg of weight class S averages 40 grams and an egg of weight class L 60 grams. (Portie-online | Rijksinstituut voor Volksgezondheid en Milieu (RIVM)).

4.4 ng/kg body weight per week to determine if the exposure poses a health risk (see chapter 5). Box 4 provides an example of a calculation of the exposure to PFAS through the consumption of two eggs per week.

Box 4: *Example calculation of the exposure to PFAS through the consumption of two eggs per week*

The summed concentration of PFAS is 10 ng PEQ per gram. An egg of 50 grams then contains 50 x 10 = 500 ng PEQ. When two such eggs are consumed per week, the exposure to PFAS equals 2 x 500 = 1000 ng PEQ per week, and 1000 ÷ 73 = 13.7 ng PEQ/kg body weight per week.

The body weight of 73 kg is the weighted average body weight of the respondents aged 1 to 79 years in the Dutch National Food Consumption Survey (DNFCS) of 2012–2016 (van Rossum et al., 2020). In the latest version of this survey of 2019-2021, the weighted average body weight was similar (72 kg). For the purpose of comparison to the previous risk assessment of home-produced eggs in the region around Chemours (Boon et al., 2024), 73 kg was used in the current study. Furthermore, the exposure to PFAS through food and drinking water in the Netherlands, which is used to assess the risk of exposure to PFAS through home-produced eggs (see chapter 5), was based on the food consumption data of the DNFCS of 2012-2016 (Schepens et al., 2023).

No separate calculations were performed for children, because PFAS can have adverse health effects after exposure over a longer time period (see Box 2 in chapter 1). Since children consume relatively more per kg body weight, they will have a higher exposure to PFAS than the total population. However, a higher exposure to PFAS during childhood is accounted for in the derivation of the HBGV of PFAS (EFSA, 2020). Thus, the conclusion of the risk assessment is also applicable to children (see chapter 5).

3.4 Calculation of maximum number of eggs

By using the location-specific summed concentrations of PFAS, the maximum number of eggs that can be consumed per week was also calculated for each location, ensuring that the PFAS exposure from these eggs alone does not exceed the HBGV. This calculation does not take into account the additional exposure to PFAS through other food and drinking water (Schepens et al., 2023). This is addressed in the risk assessment (see chapter 5).

To calculate the maximum number of eggs, the HBGV of PFAS of 4.4 ng/kg body weight per week was first multiplied by an average body weight of 73 kg (see section 3.3), resulting in a maximum weekly exposure to PFAS of 321 ng PEQ. This exposure was then divided by the location-specific summed concentrations of PFAS in an egg weighing 50 grams to calculate the maximum number of eggs that can be consumed for each location. Box 5 (see next page) provides an example of such a calculation.

Box 5: *Example calculation of the maximum number of eggs*

The maximum number of eggs that can be consumed before exceeding the HBGV was calculated by dividing the maximum weekly exposure to PFAS of 321 ng PEQ, based on an average body weight of 73 kg, by the location-specific summed concentration of PFAS in a 50-gram egg.

First, the summed concentration of PFAS, expressed in ng PEQ per gram, was multiplied by 50 grams to calculate the summed concentration in one egg. With a fictitious summed concentration in a sample of 3 ng PEQ per gram, the summed concentration in one egg equals 3 x 50 = 150 ng PEQ. The maximum number of eggs that can then be consumed is 321 ng PEQ ÷ 150 ng PEQ = two eggs per week.

4 Results and uncertainties

4.1 Concentrations of PFAS

The samples were analysed for 18 PFAS (see section 2.2). All PFBA concentrations were reported as 'not determined', because this PFAS could not be determined due to a high background signal. Therefore, the calculated location-specific summed concentrations of PFAS were based on 17 PFAS.

In order to get an overview of the reported PFAS concentrations in the samples, a heatmap with hierarchical clustering is provided (see Figure 2 on the next page). Box 6 explains what such a heatmap entails.

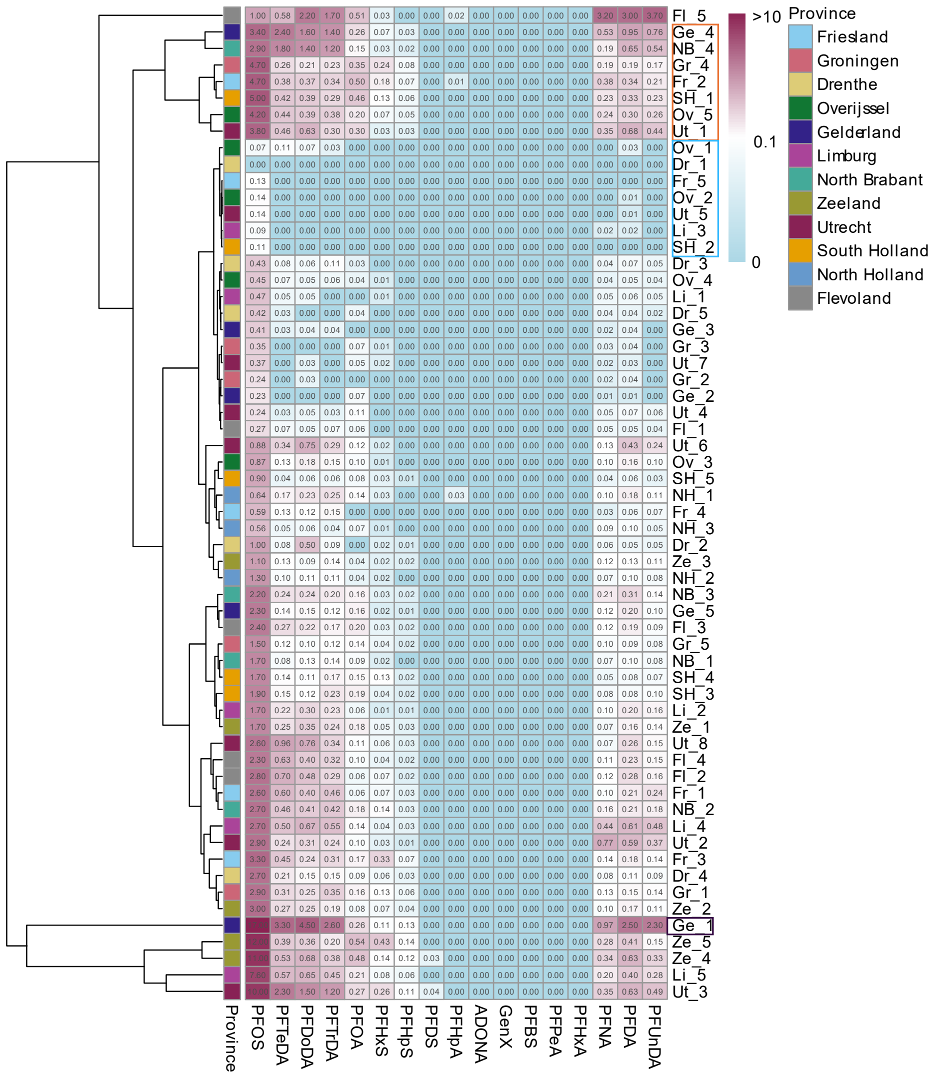
Box 6: *Heatmap*

A heatmap with hierarchical clustering shows a matrix in which colours represent value intensity. Hierarchical clustering groups similar data, visualised using dendrograms along the axes. The length of the branches represents the measure of dissimilarity between clusters, where longer branches indicate greater dissimilarity. Thus, a heatmap can be used to spot clusters of similar or contrasting values, and the relationships between them. The method simplifies complex datasets into an interpretable visual format, aiding in the detection of trends and relationships that might not be immediately obvious from the raw data.

Each cell in the heatmap represents a PFAS concentration. The colours in the cells provide insight into the PFAS concentrations, ranging from a low concentration in blue to a high concentration in red. The concentrations reported as '< LOD' or '< LOQ' are shown as 0 ng per gram (i.e. blue; see also section 3.1). Columns represent the various PFAS. Rows represent the locations depicted on the right-hand side of the heatmap and their corresponding Dutch province on the left-hand side. The dendrogram on the left-hand side shows which locations have similar reported PFAS concentrations in the egg samples (see also Box 6). For example, the samples from seven locations in the provinces of Gelderland (Ge_4), North Brabant (NB_4), Groningen (Gr_4), Friesland (Fr_2), South Holland (SH_1), Overijssel (Ov_5), and Utrecht (Ut_1) had similar PFAS concentration patterns (see the top-end of Figure 2). The same held true for the samples from seven locations in the provinces of Overijssel (Ov_1 and Ov_2), Drenthe (DR_1), Friesland (Fr_5), Utrecht (UT_5), Limburg (Li_3), and South Holland (SH_2). In these seven samples, hardly any PFAS were detected (see the top-end of Figure 2). On the other hand, the sample from one location in the province of Gelderland (GE_1) had a unique pattern with high concentrations (> 1 ng per gram) of five PFAS (PFOS, perfluoro-tetradecanoic acid (PFTeDA), perfluorododecanoic acid (PFDoDA), perfluorotridecanoic acid (PFTrDA), perfluorodecanoic acid (PFDA), and perfluoroundecanoic acid (PFUnDA)) (see the bottom-end of Figure 2).

The heatmap also shows whether concentration patterns are similar within a province. In that case, these provinces cluster together.

Figure 2 Heatmap showing PFAS concentrations in ng per gram of egg for 17 PFAS.[a]



Rows are locations and colour annotated by province. Each location is annotated by a province abbreviation followed by a number. Columns represent the PFAS. Values inside the matrix are coloured blue if PFAS concentration equals 0 ng per gram (meaning below limit of detection or below the limit of quantification) turning white and red when concentrations increase. Similar concentration patterns are clustered across both rows and columns. The orange, blue and black boxes around locations are described in the text.
Dr: Drenthe; Fl: Flevoland; Fr: Friesland; Ge: Gelderland; Gr: Groningen; Li: Limburg; NB: North Brabant; ng: nanogram; NH: North Holland; Ov: Overijssel; PFAS: per- and polyfluoroalkyl substances; SH: South Holland; Ut: Utrecht; Ze: Zeeland.
[a] The names of the PFAS can be found in Table 1 in section 2.2.

The heatmap shows that this was not the case.

In addition, this heatmap shows that:
- PFPeA, perfluorohexanoic acid (PFHxA), perfluorobutanesulfonic acid (PFBS), GenX, and ADONA were reported as '< LOD' or '< LOQ' in all samples;
- PFOS was detected in all samples but one, and was at the highest concentration in most samples;
- perfluoroheptanoic acid (PFHpA) was detected in three samples only, while perfluorodecane sulfonate (PFDS) was detected in two samples;
- perfluorononanoic acid (PFNA), PFDA, and PFUnDA had very similar concentrations across all samples; and
- at one location in the province of Drenthe (Dr_1), no PFAS were detected.

Appendix B provides an overview of the location-specific individual PFAS concentrations and the summed concentrations, both expressed as PEQ. This information is also visualised in Figure 3 (see the next page). The summed concentrations in the samples ranged from 0.0 to 101 ng PEQ per gram. No clear differences were observed in summed concentrations between the provinces (see Figure 3). In most provinces, both locations with high and locations with low summed PFAS concentrations were observed. Overall, locations with the highest summed concentrations were observed in the provinces of Gelderland, Flevoland, and Utrecht, while locations with lower concentrations were observed in the provinces of Drenthe and North Holland.

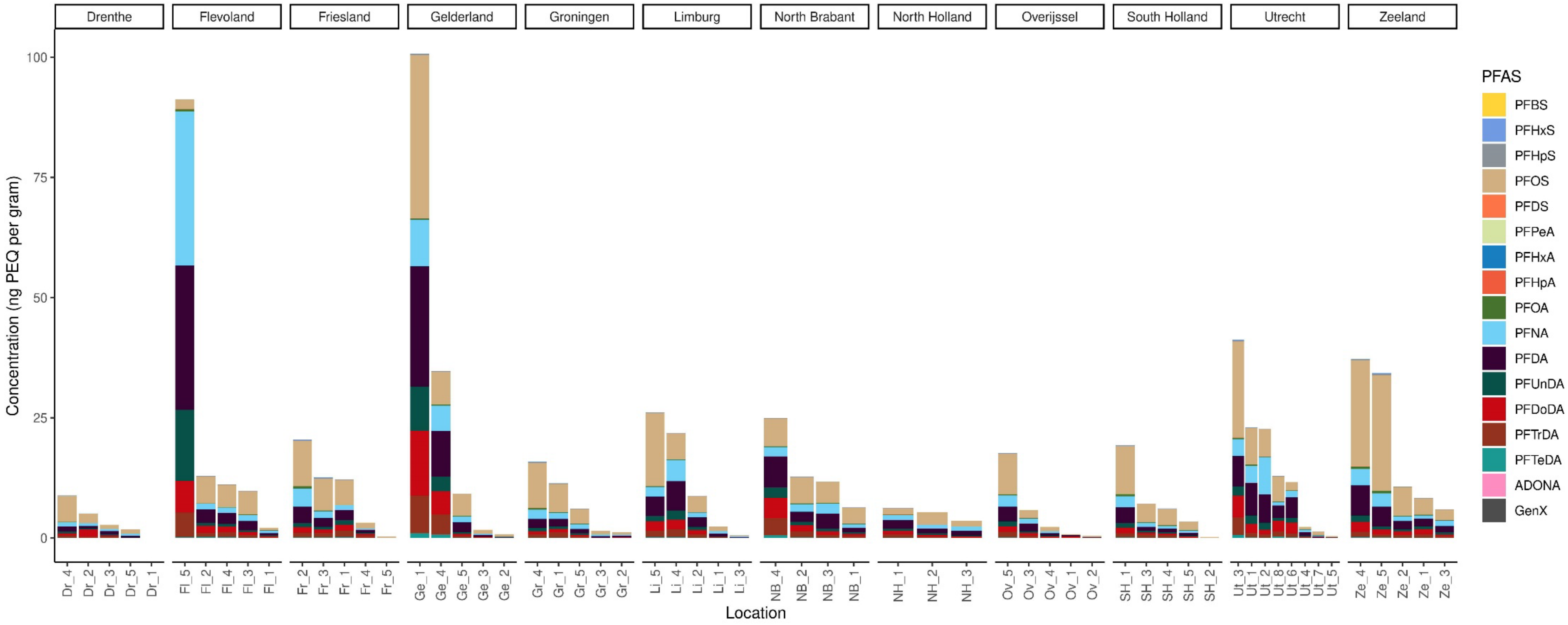
For each location, the percentage contribution of individual PFAS to the summed concentrations was calculated to detect the main contributors to the exposure to PFAS through the consumption of home-produced eggs (see Appendices C and D, and Figure 4 on page 25). At 49 locations, PFOS was the main contributor to the summed concentrations, ranging from 29 to 100 percent. With the exception of one location in the province of Flevoland (Fl_5), PFOS belonged to the top 3 PFAS that contributed most to the summed concentration per location. At eight locations, PFDA was the main contributor with percentages ranging from 26 percent to 37 percent, and at 57 locations, it belonged to the top 3 PFAS (mostly second-largest). PFNA was the main contributor at two locations with 34 percent and 35 percent, and was in the top 3 PFAS at 44 locations (mostly third-largest). Other PFAS in the top 3 were PFDoDA (10 locations), PFTrDA (two locations), and PFUnDA (one location).

4.2 Exposure to PFAS for five consumption frequencies

Using the location-specific summed concentrations (see Appendix B), the exposure to PFAS was calculated when a person consumes one, two, four, or seven eggs per week, or one egg per month (see section 3.3). The results are provided in Appendix E and Figure 5 (see page 26).

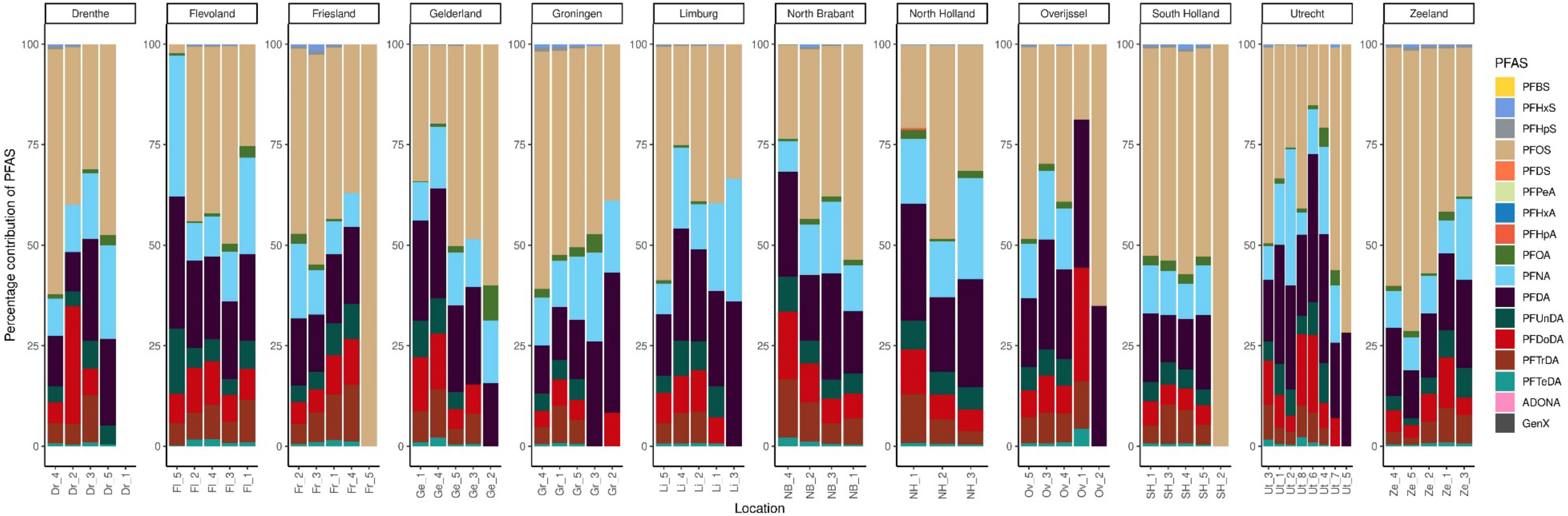
Assuming a consumption frequency of one egg per month, the exposure to PFAS in eggs from six locations exceeded the HBGV of 4.4 ng PEQ/kg body weight per week (see Figure 5).

Figure 3 Concentrations of individual PFAS[a] and the summed concentrations of PFAS (both in ng PEQ per gram) in home-produced eggs per location.



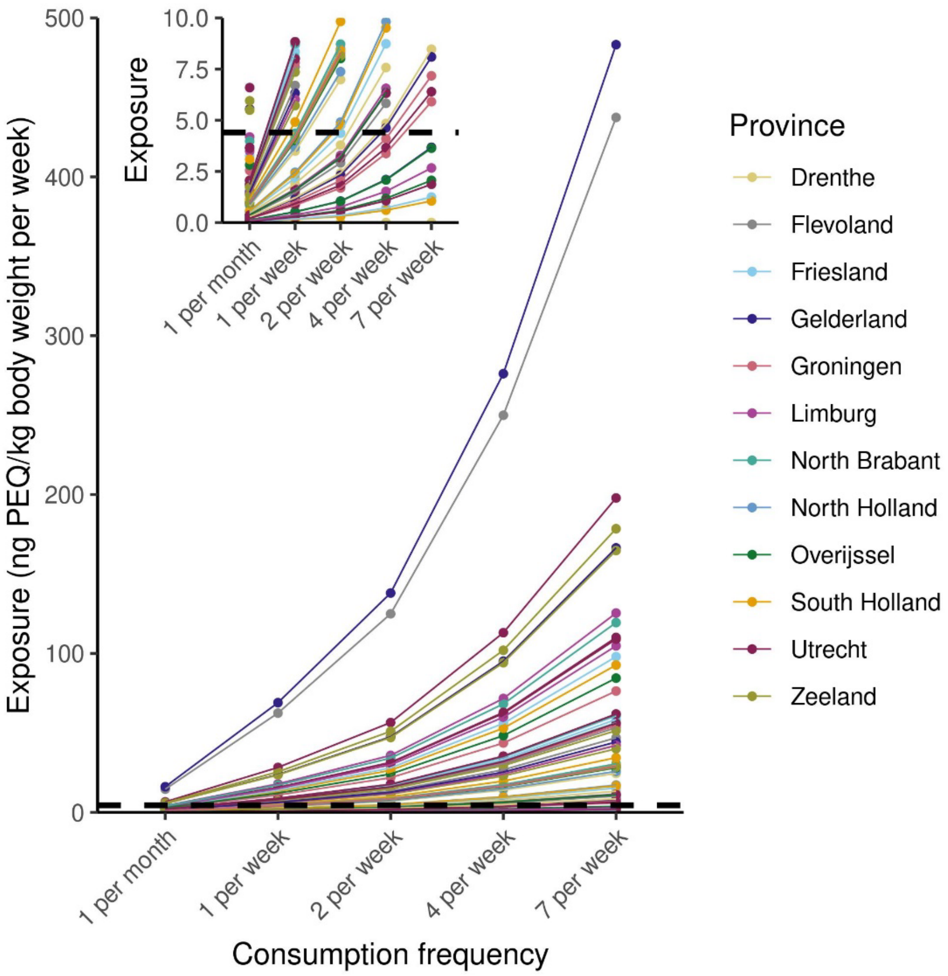
Each location is annotated by a province abbreviation followed by a number and grouped by province. PFAS are annotated by different colours. Dr: Drenthe; Fl: Flevoland; Fr: Friesland; Ge: Gelderland; Gr: Groningen; Li: Limburg; NB; North Brabant; ng: nanogram; NH: North Holland; Ov: Overijssel; PEQ: PFOA-equivalents; PFAS: per- and polyfluoroalkyl substances; SH: South Holland; Ut: Utrecht; Ze: Zeeland.
[a] The names of the PFAS can be found in Table 1 in section 2.2.

Figure 4 Contribution of different PFAS[a] in percentages to the summed concentration of PFAS (in ng PEQ per gram) in home-produced eggs per location.



Each location is annotated by a province abbreviation followed by a number and grouped by province. PFAS are annotated by different colours. Dr: Drenthe; Fl: Flevoland; Fr: Friesland; Ge: Gelderland; Gr: Groningen; Li: Limburg; NB; North Brabant; ng: nanogram; NH: North Holland; Ov: Overijssel; PEQ: PFOA-equivalents; PFAS: per- and polyfluoroalkyl substances; SH: South Holland; Ut: Utrecht; Ze: Zeeland.
[a] The names of the PFAS can be found in Table 1 in section 2.2.

Figure 5 PFAS exposure for five consumption frequencies of home-produced eggs.



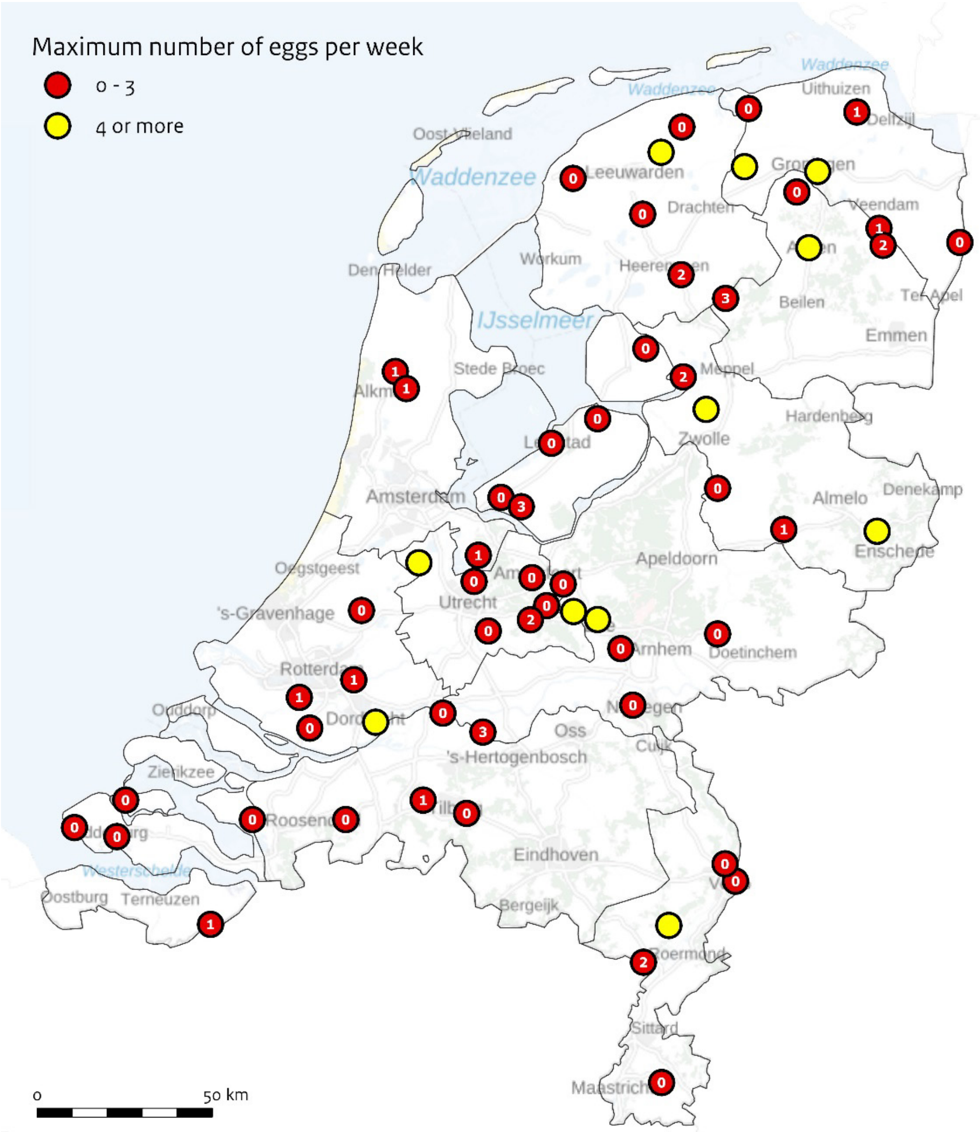
Every point represents a location, connected by lines. Provinces are annotated by colour. The dashed line represents the health-based guidance of PFAS of 4.4 ng/kg body weight per week. The insert graph on top is a zoom of the main graph, where the y-axis is reduced to 0-10 ng PEQ/kg body weight per week. When a point is not connected with a line, this means that a higher consumption frequency results in an exposure of more than 10 ng PEQ/kg body weight per week.
ng: nanogram; PEQ: PFOA-equivalents; PFAS: per- and polyfluoroalkyl substances

By increasing the consumption frequency to one egg per week, the exposure to PFAS in eggs from 31 locations exceeded this guidance value. For two and four eggs per week, the number of locations with an exposure above the HBGV increased to 41 and 49, respectively. For seven eggs per week, the exposure to PFAS from eggs exceeded the HBGV at 52 out of the 60 locations (see Figure 5).

4.3 Maximum number of eggs

In addition to the calculations of the exposure to PFAS through various consumption frequencies, the maximum number of eggs that can be consumed per week without exceeding the HBGV through these eggs alone was calculated for each location (see section 3.4). The results are presented in Figure 6.

Figure 6 Map of the Netherlands in which each circle represents a location at which home-produced eggs were collected.



The colour of the circles indicates the maximum number of eggs per week that could be consumed per location without exceeding the health-based guidance value of per- and polyfluoroalkyl substances (PFAS) of 4.4 ng/kilogram body weight per week. For locations with a maximum of three or less eggs per week, the number of eggs is indicated in the circle.

At 31 locations, people exceed the HBGV if they consume less than one egg per week (see Figure 6). At ten locations, this is the case with up to one egg per week, at five locations with up two eggs, at three locations with up to three eggs and at two locations with up to four eggs per week. At nine locations, more than four eggs per week can be consumed before exceeding the HBGV.

This calculation does not include exposure to PFAS through other food and drinking water, and it is noted that this exposure already exceeds the HBGV (Schepens et al., 2023). This is taken into account in the risk assessment (see chapter 5).

4.4 Uncertainties in the calculations

The results of the calculations described in the previous two sections were affected by several uncertainties. Most uncertainties are similar to those reported in Boon et al. (2024). The most important ones are briefly discussed below.

One uncertainty is that the eggs were collected at the end of August (see section 2.1). Since the egg production of chickens decreases as the number of daylight hours decreases, the production during the collection was likely to be lower than, for example, in mid-summer, as confirmed by several participants. This lower egg production may have affected the concentration of PFAS in the eggs. The PFAS concentration in eggs is related to the exposure to PFAS during a steady-state situation (Kowalczyk et al., 2020; Wilson et al., 2021). With a constant exposure to PFAS, the amount of PFAS in the eggs could increase with lower egg production, as the excretion route via eggs is reduced (FO, 2023). Possible seasonal changes in PFAS in eggs are studied in the follow-up study of the current report, by collecting eggs multiple times throughout the year.

Another uncertainty are the summed PFAS concentrations used in the calculations. To calculate these concentrations, the PFAS concentrations that were reported as '< LOD' or '< LOQ' were assumed to equal zero (see Table 2 in section 3.1). This assumption may have underestimated the actual summed concentrations because the undetected ('< LOD') and unquantified ('< LOQ') PFAS may actually be present in the samples. This is especially the case for concentrations reported as '< LOQ' because in those cases, it is likely that PFAS is present in the sample. However, it is expected that the summed concentrations have only be slightly underestimated by assigning zero to the undetected and unquantified concentrations. The percentage of samples with a reported concentration of '< LOQ' was only 6.3 percent (see Appendix A), and the concentrations that were quantified were high compared to the levels of the LODs and LOQs (see Appendix A).

In this study, eggs from 60 locations across the Netherlands have been analysed. Although this number is insufficient to cover all regions in the Netherlands, it is not expected that more locations will change the risk assessment (see chapter 5). Results show that high PFAS concentrations in home-produced eggs can occur across the country.

In this study, PFAS were analysed in raw eggs, while mostly fried or boiled eggs are consumed. The preparation of eggs before consumption could have an effect on the presence of PFAS, and thus on the calculated exposure to PFAS. It is still largely unknown what effect food preparation has on PFAS concentrations (EFSA, 2020). On the other hand, it is known that PFAS only break down at very high temperatures: from about 400 °C (Bokkers et al., 2019). On these grounds, it is expected that this uncertainty had little to no effect on the calculations.

In summary, especially the laying frequency could have influenced the results of the calculations. However, it is expected that this uncertainty has not affected the risk assessment or the conclusion of the current study considering the magnitude of the summed concentrations of PFAS in the home-produced eggs.

5 Risk assessment of PFAS in home-produced eggs

This chapter assesses the risk of consuming the home-produced eggs included in the current study. The risk assessment was performed in the same way as reported in Boon et al. (2024). In section 4.3, the calculated exposure to PFAS from the eggs was compared to the HBGV of PFAS (see Box 2 in chapter 1). However, the exposure to PFAS through other food and drinking water, referred to as the background exposure, should also be considered in order to assess the health risk of PFAS when consuming these eggs. To assess this risk, the current chapter combines the exposure to PFAS through consumption of home-produced eggs with the background exposure.

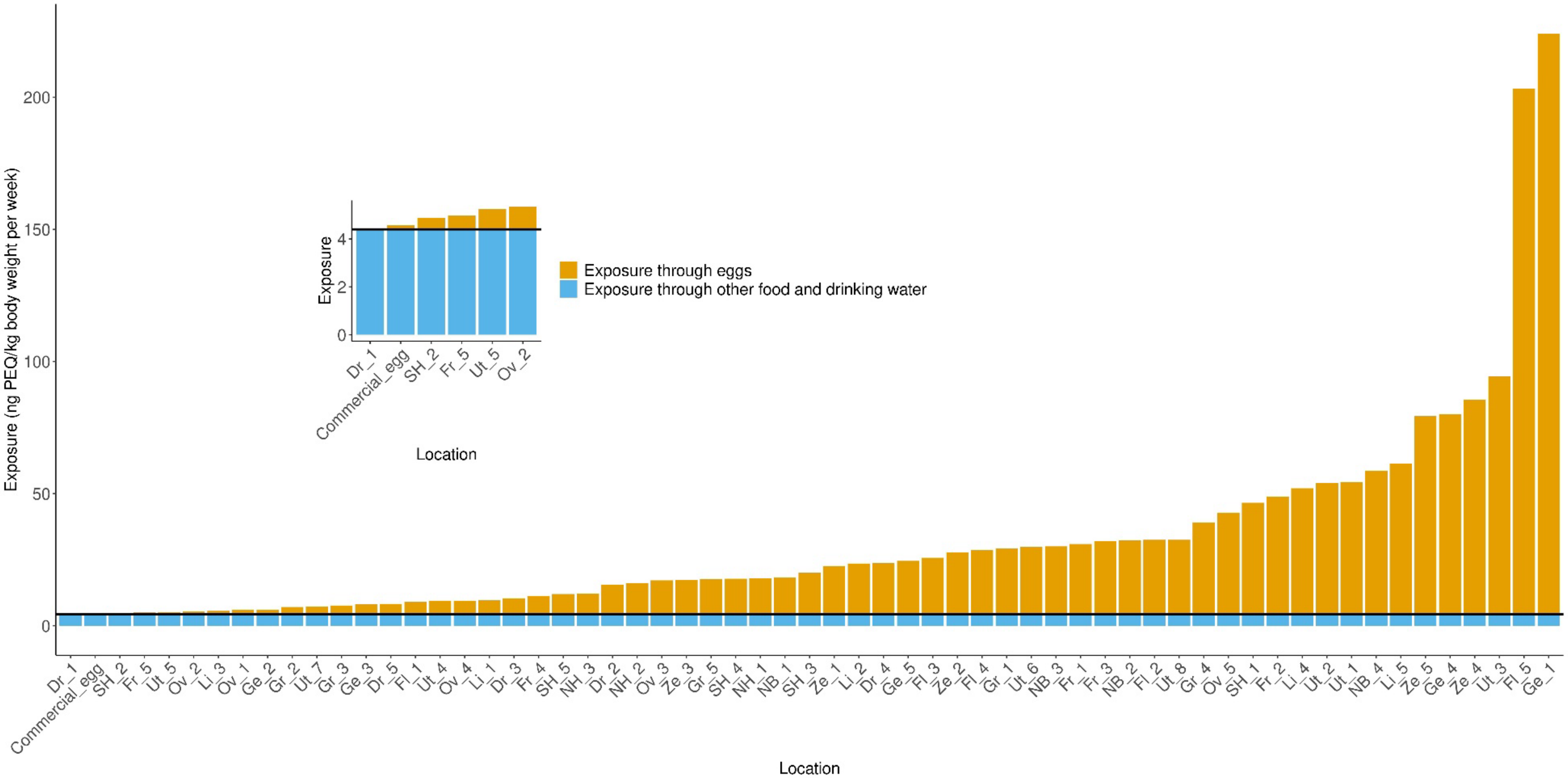
First, the background exposure to PFAS, i.e. without the contribution of eggs, was calculated. To this end, we used the PFAS exposure through food and drinking water as calculated in 2023 for the Dutch population (Schepens et al., 2023). In that study, food consumption data from the DNFCS 2012-2016 were combined with PFAS concentrations in food products, including commercial eggs (eggs from shops or markets), and drinking water. The results showed that the average exposure to PFAS was 4.6 ng PEQ/kg body weight per week when people consumed drinking water produced from groundwater or 5.9 ng PEQ/kg body weight per week when people consumed drinking water produced from surface water. The high exposure (95th percentile) was 12 or 14 ng PEQ/kg body weight per week, respectively.

The background exposure to PFAS was calculated on the basis of the exposure through food and drinking water produced from groundwater (= 4.6 ng PEQ/kg body weight per week). Commercial eggs contributed 3.7 percent to the average exposure to PFAS in this situation, amounting to an average exposure of 0.17 ng PEQ/kg body weight per week. When excluding consumption of commercial eggs, the average background exposure to PFAS resulted in 4.4 ng PEQ/kg body weight per week (= 4.6 - 0.17).

Second, the exposure to PFAS through home-produced eggs was calculated, assuming that the amount of eggs consumed as reported in the DNFCS (on average about 2-3 eggs per week) is completely replaced by that of home-produced eggs. The exposure to PFAS through commercial eggs was based on a summed concentration of 0.078 ng PEQ per gram (Schepens et al., 2023). The summed concentrations in the home-produced eggs were a factor of 2.8 to 1292 higher, except for those from one location in the province of Drenthe (Dr_1), in which no PFAS were detected (see section 4.1). This means that the exposure to PFAS through the home-produced eggs from 59 locations would be a factor of 2.8 to 1292 higher, ranging from 0.5 to 220 ng PEQ/kg body weight per week.

Last, these exposure estimates per location were added to the background exposure of 4.4 ng/kg body weight per week (see Figure 7 on the next page). Note that for people who consume drinking water

Figure 7 Exposure to PFAS in ng PEQ/kg body weight per week through other food and drinking water (background exposure; blue) and through commercial eggs or home-produced eggs (orange) from the 60 locations.



Exposure is based on the calculation of the exposure to PFAS through food and drinking water from ground water (Schepens et al., 2023). The black line indicates the health-based guidance value of PFAS (4.4 ng/kg body weight per week). The insert shows an enlargement of exposure at five locations with the lowest exposure and for commercial eggs.
Dr: Drenthe; Fl: Flevoland; Fr: Friesland; Ge: Gelderland; Gr: Groningen; kg: kilogram; Li: Limburg; NB; North Brabant; ng: nanogram; NH: North Holland; PEQ: PFOA-equivalents; PFAS: per- and polyfluoroalkyl substances; Ov: Overijssel; SH: South Holland; Ut: Utrecht; Ze: Zeeland

produced from surface water, the exposure to PFAS through eggs will be the same, but the background exposure is slightly higher.

The average exposure to PFAS (through eggs plus background) for the two locations with the lowest summed concentrations of PFAS (Dr_1 and SH_2) was 4.4 and 4.9 ng PEQ/kg body weight per week, respectively, and for the two locations with the highest summed concentration of PFAS (Fl_5 and Ge_1) the exposure amounted to 203 and 224 ng PEQ/kg body weight per week, respectively.

This risk assessment is based on the average exposure to PFAS in the Netherlands. An individual's exposure may be higher or lower depending on their consumption pattern. These results show that, in most cases, the exposure to PFAS through food and drinking water increases significantly when home-produced eggs are consumed and can add substantially to an already high exposure to PFAS through other food and drinking water. With an increasing exposure to PFAS above the HBGV, the risk of harmful health effects from PFAS will also increase. Whether these effects will actually occur also depends on factors such as lifestyle, including diet and exercise, and individual differences in susceptibility to diseases.

The risk assessment is based on the assumption that PFAS have been present in the eggs at the calculated summed concentrations for an extended period. Whether these concentrations have been lower in the past is unknown. However, considering the finding that most home-produced eggs from the investigated locations contain significantly more PFAS than commercial eggs, and that other studies have also shown that PFAS concentrations in home-produced eggs can be elevated (see also section 6.1), it is likely that the PFAS concentrations in these eggs have been high for some time.

6 Discussion

This chapter compares the concentrations of PFAS in home-produced eggs from the current study to those in home-produced eggs from other studies (see section 6.1). The concentrations in the home-produced eggs are also compared to the legal maximum levels (MLs) for PFAS in eggs in the European Union (EU; see section 6.2). Additionally, the possible sources through which PFAS can enter home-produced eggs are briefly discussed (see section 6.3).

6.1 PFAS concentrations in home-produced and commercial eggs from other studies

Home-produced eggs in the Netherlands

In 2024, RIVM published a study on PFAS concentrations in home-produced eggs from 31 locations in seven municipalities from the region South-Holland South and one location in the province of North Brabant (Boon et al., 2024). Out of these, 28 locations were selected because of their vicinity to Chemours, a chemical company that used PFAS in its production processes. Summed PFAS concentrations in the eggs from all 31 locations ranged from 0.43 to 77 ng PEQ per gram, compared to 0 to 101 ng PEQ per gram in this study. At 22 locations (71 percent), eggs could be consumed less than once a week without exceeding the HBGV of PFAS through eggs alone. At two locations (6.5 percent), four or more eggs could be consumed without exceeding the HBGV. Corresponding numbers in the current study were 31 (52 percent) and 11 (18 percent) locations, respectively. It was noted that the eggs in the 2024 study were collected in the autumn (later than in the current study), which could have influenced the PFAS concentrations found in these eggs (see section 4.4). In the 2024 study, PFOS was the main contributor to the summed concentrations of PFAS, followed by PFDA and PFNA. The same top 3 was observed in the current study.

As Chemours has used PFOA until 2012, the concentrations of PFOA observed in eggs in the current study were compared to those in the eggs at the 28 locations in the vicinity of the Chemours chemical plant. The median concentration of PFOA was 0.10 ng per gram and 0.69 ng per gram, respectively, and was significantly ($p < 0.001$; Wilcoxon rank sum test, $W=1557$) higher in the 2024 study. For the purpose of comparison, the median concentrations of 1.7 and 2.1 ng per gram for PFOS ($p > 0.05$; $W=1017$), 0.16 and 0.21 ng per gram for PFDA, and ($p > 0.05$; $W=1039$) and 0.10 and 0.13 ng per gram for PFNA ($p < 0.05$; $W=1080$), respectively, were only slightly higher in the 2024 study. This indicates that eggs from the vicinity of Chemours are likely to contain more PFOA than eggs from other locations in the Netherlands.

In another study from 2016, PFAS concentrations in home-produced eggs collected from 73 locations in the Netherlands were reported (Zafeiraki et al., 2016). These were locations without a known source of PFAS contamination nearby, as in the current study. The eggs were collected in 2013-2014, boiled, and then the yolk of multiple eggs from the same location was analysed as a composite sample for 10 PFAS. In 59 out of the 73 samples, at least one PFAS was detected at a concentration above the limit of quantification (LOQ) of 0.50 ng per gram. In the 2016 study, no summed concentrations of PFAS expressed in PFOA-equivalents (PEQ) were reported. These summed concentrations were calculated by Boon et al., 2024 and ranged from 0 to 30 ng PEQ per gram.[9] These summed concentrations seem lower than the summed concentrations in the current study (see Appendix B; 0-101 ng PEQ per gram). However, the LOQ in the 2016 study was higher than the LOQ in the current study (0.50 ng per gram versus 0.01–0.10 ng per gram; see section 2.2). In the current study, 38 percent of the samples had a PFAS concentration between the LOQ and 0.50 ng per gram (see Appendix A). Therefore, the summed concentrations from the 2016 study are likely to be an underestimation of the actual summed concentrations in the examined home-produced eggs. Furthermore, in the 2016 study, 10 PFAS were analysed, compared to 17 (excluding PFBA; see section 4.1) in the current study. This could also have contributed to lower summed PFAS concentrations.

Journalistic investigations into PFAS in home-produced eggs in the Netherlands
Recently, high PFAS concentrations in home-produced eggs have been reported in the Dutch media. NRC (Nieuwe Rotterdamse Courant; a Dutch newspaper) investigated home-produced eggs from the area around Chemours in Dordrecht[10], and NOS (The Dutch Broadcasting Foundation) conducted tests on home-produced eggs from 12 locations in the Netherlands without a known source of PFAS contamination nearby.[11] Both investigations showed that some of the sampled eggs contained more PFAS than the legal MLs in the EU (see section 6.2). As the PFAS concentrations were not reported, the results of the current study cannot be compared to these findings. Additionally, no information was published regarding the LOQ used.

Commercial eggs in the Netherlands
Two studies have examined PFAS in commercial eggs available in shops and on markets in the Netherlands. In 2023, RIVM calculated the PFAS exposure in the Netherlands through food and drinking water, including commercial eggs (Schepens et al., 2023; see also chapter 5). In this study, the average summed concentration of PFAS in these eggs was 0.078 ng PEQ per gram. In 2024, the Office of Risk Assessment and Research (BuRO) of the Netherlands Food and Consumer Product Safety Authority (NVWA) published a risk assessment of PFAS in home-produced eggs (BuRO, 2024). This report also presents the summed concentrations of 18 PFAS in 140 composite samples of commercial eggs. These eggs were sampled between 2018 and 2022 as part of the monitoring programme conducted by WFSR on behalf of the Ministry of Agriculture, Fisheries, Food Security and Nature. The samples included

[9] To calculate the summed concentrations, the PFAS concentrations in egg yolk were first converted to PFAS concentrations in the whole egg. Since PFAS accumulate in the egg yolk, this was calculated on the basis of a weight ratio of one-third yolk and two-thirds egg white. So, the concentration of a PFAS in the whole egg is three times lower than in the yolk. Subsequently, the summed concentration of PFAS in the 73 samples was calculated using the RPF approach (see section 3.2).
[10] https://www.nrc.nl/nieuws/2023/08/31/eieren-van-hobbykippen-uit-sliedrecht-zijn-zwaar-vervuild-met-pfas-van-chemours-a4173207
[11] https://nos.nl/artikel/2505086-ook-pfas-in-hobby-eieren-ver-buiten-regio-dordrecht

raw eggs without shells (personal communication by WFSR) as do the samples in the current study. The average summed concentration of PFAS in these eggs was 0.058 ng PEQ per gram. Both studies show that the PFAS concentrations in commercial eggs can be significantly lower than in home-produced eggs.

There are three common types of commercial eggs available in shops and on markets: organic, free-range, and barn eggs. The first two types come from chickens that can go outdoors, while barn eggs come from hens that are cooped up. Differences in living conditions may have influenced the PFAS concentrations in the eggs from these chickens (see also section 6.3). However, such a comparison was not possible, because the, the number of eggs analysed per type was too limited or information about the type of egg analysed was lacking in the studies by RIVM and BuRO. Additionally, in recent years, the Netherlands has had mandatory confinement periods for commercial poultry at various times and locations due to avian influenza. This may also have affected the PFAS concentrations in commercial eggs as described above.

Overall, studies investigating PFAS in eggs show that the summed concentrations of PFAS in home-produced eggs in the Netherlands can be (significantly) higher than in commercial eggs.

6.2 Comparison to MLs

Since 1 January 2023, legal maximum levels (MLs) for certain foods have been in effect in the EU to reduce the exposure to PFAS through food (Regulation (EU) 2023/915).[12] Foods for which MLs have been established include fishery products and bivalve molluscs, meat and edible offal, and eggs. These foods may not be marketed if the ML of the EFSA-4 (PFOS, PFOA, PFNA, and PFHxS; see Box 2 in chapter 1) and/or the ML of at least one of the EFSA-4 is exceeded. The MLs for eggs are 1.0 ng per gram for PFOS, 0.30 ng per gram for PFOA, 0.70 ng per gram for PFNA, and 0.30 ng per gram for PFHxS. For the sum of these four PFAS, the ML is 1.7 ng per gram (note that this ML is lower than the sum of the individual MLs). The MLs apply only to commercial eggs, i.e. not for home-produced eggs. Furthermore, the ML for the EFSA-4 is based on summing the concentrations of the four PFAS, assuming equal potency, so without using RPFs.

On the basis of equal potency, the summed concentrations of the EFSA-4 in the home-produced eggs ranged from 0 to 18 ng per gram (see Appendix F). Eggs from 33 locations exceeded the ML for the EFSA-4 (see Table 4 on the next page). On the basis of the individual MLs, eggs from 34 locations had a PFOS concentration above the ML, while eggs from six, three and two locations exceeded the MLs for PFOA, PFNA, and PFHxS, respectively. PFAS concentrations in eggs from 25 locations were at or below all five MLs.

Even though the PFAS concentrations in the eggs of 25 locations were at or below the MLs, it was shown that consuming home-produced eggs can result in a significant increase in the exposure to PFAS through food

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32023R0915

Table 4 Number of locations with PFAS concentrations in eggs above the MLs[a] for four individual PFAS and for the EFSA-4 in the EU.

Number of locations above the MLs[b]				
PFOS	**PFOA**	**PFNA**	**PFHxS**	**SUM EFSA-4[c]**
34	6	3	2	33

EU: European Union; ML: maximum levels; PFAS: per- and polyfluoroalkyl substances
[a] The MLs for eggs are 1.0 ng per gram for PFOS, 0.30 ng per gram for PFOA, 0.70 ng per gram for PFNA, 0.30 ng per gram for PFHxS, and 1.7 ng per gram for the EFSA-4. This last ML is based on summing the concentrations of the four PFAS assuming equal potency.
[b] The names of the PFAS can be found in Table 1 in section 2.2.
[c] The EFSA-4 consists of PFOS, PFOA, PFNA, and PFHxS, the PFAS on which the health-based guidance value of PFAS is based (see Box 2 in chapter 1).

and drinking water (see chapter 5). This shows that the consumption of a food with a concentration at or below the ML does not necessarily result in an exposure that is below the HBGV. This will depend on how much of such a food is consumed and on the level of exposure through other food and drinking water. An ML is therefore not an HBGV and should not be used as such.

An ML is a product standard, which is established on the basis of feasibility, applying the ALARA (As Low As Reasonably Achievable) principle. This principle is used for substances such as PFAS, whose presence cannot be easily prevented or reduced in the short term. This principle ensures that the amounts of these substances in food are as low as possible without jeopardising the food supply. The ML for a food product is often equated to the 95th percentile of current concentrations in this product in the EU, where concentrations below the LOD or below the LOQ are considered to be zero. Food products with the highest 5 percent of concentrations are then removed from the EU market. By regularly evaluating and lowering the MLs, concentrations in food products will eventually become so low that their consumption is no longer harmful to health. This is a process that can take considerable time. Due to this process, which is still in its early stages for PFAS, it is possible for a food product to meet the ML while its consumption may result in an exposure above the HBGV. Furthermore, it is important to note that the EU MLs are based on the EFSA-4, while other PFAS in the eggs also contribute to the overall exposure to PFAS.

6.3 Sources of PFAS

The source or sources of PFAS in home-produced eggs are currently unknown. Research and consultancy firm Arcadis recently published a study in which various types of chicken feed, water, soil, bedding, mealworms, vitamins, medications, and earthworms were investigated as potential sources of PFAS in home-produced eggs from the region around Chemours (Arcadis, 2024). This study showed that earthworms might be a significant source of PFAS in the home-produced eggs. The authors noted, however, that it is unclear whether this is the only source of exposure. As part of the current study, a nationwide investigation is being conducted to gather more information about the possible source or sources of PFAS in home-produced eggs. Results are expected in the second half of 2025.

7 Conclusion

In the current study, a risk assessment of PFAS through the consumption of home-produced eggs was performed. These eggs were collected in August 2024 (see section 2.1) from 60 locations in the Netherlands.

Calculations of PFAS exposure through the consumption of these eggs showed that eggs from 31 locations contained such high PFAS concentrations that even consuming just one egg or less per week resulted in an exposure exceeding the health-based guidance value (HBGV) of PFAS. Eggs from other locations could be consumed maximally once (ten 10 locations) or twice (five locations) per week, or at most three (three locations) or four times per week (two locations) without exceeding this guidance value. At nine locations, more than four eggs per week could be consumed. If the exposure exceeds the HBGV over a longer period of time, it can be harmful to health.

Through consuming home-produced eggs in the Netherlands, the exposure to PFAS can be high. This exposure adds to the already high exposure to PFAS through other food and drinking water (Schepens et al., 2023)'. Therefore, it is recommended not to consume home-produced eggs. Currently, there is an advice not to eat home-produced eggs from the region around Chemours (South-Holland South and the municipality of Altena).[13] The conclusion of the current study extends this advice to any home-produced eggs from the Netherlands. This advice can only be relaxed when the PFAS concentrations in these eggs decrease significantly. Since eggs from a shop or market contain significantly less PFAS, they are an alternative for home-produced eggs.

Currently, a nationwide investigation is being conducted to gather information about the possible source or sources of PFAS in home-produced eggs. Results are expected in the second half of 2025.

[13] https://www.ggdzhz.nl/nieuws/alle-eieren-hobbykippen-regio-zhz-bevatten-te-veel-pfas-advies-eet-deze-eieren-niet

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Appendix A PFAS concentrations (in ng per gram) in home-produced eggs per location

https://www.rivm.nl/bibliotheek/rapporten/2025-0011-Appendices-A-B-D.xlsx

Appendix B PFAS concentrations (in ng PEQ per gram) in home-produced eggs per location

https://www.rivm.nl/bibliotheek/rapporten/2025-0011-Appendices-A-B-D.xlsx

Appendix C Top 3 contributing PFAS per location

Location	Summed concentration (ng PEQ per gram)	Top 3 PFAS[a,b] (contribution to the summed concentration in percentage)		
		1	2	3
Ge_1	101	PFOS (34)	PFDA (25)	PFDoDA (13)
Fl_5	91.2	PFNA (35)	PFDA (33)	PFUnDA (16)
Ut_3	41.3	PFOS (49)	PFDA (15)	PFDoDA (11)
Ze_4	37.2	PFOS (59)	PFDA (17)	PFNA (9.1)
Ge_4	34.7	PFDA (27)	PFOS (20)	PFNA (15)
Ze_5	34.4	PFOS (70)	PFDA (12)	PFNA (8.1)
Li_5	26.2	PFOS (58)	PFDA (15)	PFNA (7.6)
NB_4	24.9	PFDA (26)	PFOS (23)	PFDoDA (17)
Ut_1	23	PFOS (33)	PFDA (30)	PFNA (15)
Ut_2	22.7	PFNA (34)	PFDA (26)	PFOS (26)
Li_4	21.9	PFDA (28)	PFOS (25)	PFNA (20)
Fr_2	20.4	PFOS (46)	PFNA (19)	PFDA (17)
SH_1	19.3	PFOS (52)	PFDA (17)	PFNA (12)
Ov_5	17.6	PFOS (48)	PFDA (17)	PFNA (14)
Gr_4	15.9	PFOS (59)	PFNA (12)	PFDA (12)
Ut_8	12.9	PFOS (40)	PFDA (20)	PFDoDA (18)
Fl_2	12.9	PFOS (43)	PFDA (22)	PFDoDA (11)
NB_2	12.8	PFOS (42)	PFDA (16)	PFNA (13)
Fr_3	12.7	PFOS (52)	PFDA (14)	PFNA (11)
Fr_1	12.2	PFOS (43)	PFDA (17)	PFTrDA (11)
NB_3	11.8	PFOS (37)	PFDA (26)	PFNA (18)
Ut_6	11.7	PFDA (37)	PFDoDA (19)	PFOS (15)
Gr_1	11.4	PFOS (51)	PFDA (13)	PFNA (11)
Fl_4	11.1	PFOS (41)	PFDA (21)	PFDoDA (11)
Ze_2	10.7	PFOS (56)	PFDA (16)	PFNA (9.3)
Fl_3	9.8	PFOS (49)	PFDA (19)	PFNA (12)
Ge_5	9.2	PFOS (50)	PFDA (22)	PFNA (13)
Dr_4	8.8	PFOS (61)	PFDA (12)	PFNA (9.3)
Li_2	8.8	PFOS (39)	PFDA (23)	PFNA (11)
Ze_1	8.3	PFOS (41)	PFDA (19)	PFDoDA (13)
SH_3	7.2	PFOS (53)	PFDA (12)	PFNA (11)
NB_1	6.4	PFOS (53)	PFDA (15)	PFNA (12)
NH_1	6.2	PFDA (29)	PFOS (21)	PFNA (16)
SH_4	6.1	PFOS (55)	PFDA (13)	PFNA (8.6)
Gr_5	6.1	PFOS (50)	PFNA (16)	PFDA (15)
Ze_3	5.9	PFOS (37)	PFDA (22)	PFNA (20)
Ov_3	5.9	PFOS (30)	PFDA (27)	PFNA (17)
NH_2	5.4	PFOS (48)	PFDA (19)	PFNA (14)
Dr_2	5.1	PFOS (39)	PFDoDA (29)	PFNA (12)
NH_3	3.6	PFOS (31)	PFDA (27)	PFNA (25)
SH_5	3.5	PFOS (52)	PFDA (18)	PFNA (12)
Fr_4	3.2	PFOS (37)	PFDA (19)	PFTrDA (14)
Dr_3	2.8	PFOS (31)	PFDA (25)	PFNA (16)

Location	Summed concentration (ng PEQ per gram)	Top 3 PFAS[a,b] (contribution to the summed concentration in percentage)		
		1	2	3
Li_1	2.4	PFOS (39)	PFDA (24)	PFNA (22)
Ov_4	2.3	PFOS (39)	PFDA (22)	PFNA (15)
Ut_4	2.3	PFDA (32)	PFNA (22)	PFOS (21)
Fl_1	2.1	PFOS (25)	PFNA (24)	PFDA (22)
Dr_5	1.8	PFOS (48)	PFNA (23)	PFDA (22)
Ge_3	1.7	PFOS (49)	PFDA (24)	PFNA (12)
Gr_3	1.5	PFOS (47)	PFDA (26)	PFNA (22)
Ut_7	1.3	PFOS (56)	PFDA (19)	PFNA (14)
Gr_2	1.2	PFOS (39)	PFDA (35)	PFNA (18)
Ge_2	0.77	PFOS (60)	PFNA (16)	PFDA (16)
Ov_1	0.76	PFDA (37)	PFDoDA (28)	PFOS (19)
Li_3	0.56	PFDA (36)	PFOS (34)	PFNA (31)
Ov_2	0.43	PFOS (65)	PFDA (35)	-
Ut_5	0.39	PFOS (72)	PFDA (28)	-
Fr_5	0.26	PFOS (100)	-	-
SH_2	0.22	PFOS (100)	-	-
Dr_1	0.00	-	-	-

Dr: Drenthe; Fl: Flevoland; Fr: Friesland; Ge: Gelderland; Gr: Groningen; Li: Limburg; NB; North Brabant; ng: nanogram; NH: North Holland; Ov: Overijssel; PEQ: PFOA-equivalents; PFAS: per- and polyfluoroalkyl substances; SH: South Holland; Ut: Utrecht; Ze: Zeeland

[a] The names of the PFAS can be found in Table 1 in section 2.2.

[b] The three PFAS that contributed most to the summed concentration per location are listed in order of their contribution.

Appendix D Percentage contribution of the individual PFAS to the summed concentrations

https://www.rivm.nl/bibliotheek/rapporten/2025-0011-Appendices-A-B-D.xlsx

Appendix E PFAS exposure per consumption frequency and location

Location	PFAS exposure at different consumption frequencies (in ng PEQ/kg body weight)				
	1 egg per month	Number of eggs per week			
		1	2	4	7
Dr_1	0.0	0.0	0.0	0.0	0.0
Dr_2	0.82	3.5	7.0	14	24
Dr_3	0.44	1.9	3.8	7.6	13
Dr_4	1.4	6.0	12	24	42
Dr_5	0.28	1.2	2.4	4.8	8.5
Fl_1	0.34	1.5	2.9	5.8	10
Fl_2	2.1	8.8	18	35	62
Fl_3	1.6	6.7	13	27	47
Fl_4	1.8	7.6	15	30	53
Fl_5	14	62	125	250	437
Fr_1	2.0	8.4	17	33	58
Fr_2	3.3	14	28	56	98
Fr_3	2.0	8.7	17	35	61
Fr_4	0.51	2.2	4.4	8.7	15
Fr_5	0.04	0.18	0.36	0.71	1.3
Ge_1	16	69	138	276	483
Ge_2	0.12	0.53	1.1	2.1	3.7
Ge_3	0.27	1.2	2.3	4.6	8.1
Ge_4	5.6	24	48	95	166
Ge_5	1.5	6.3	13	25	44
Gr_1	1.8	7.8	16	31	55
Gr_2	0.20	0.84	1.7	3.4	5.9
Gr_3	0.24	1.0	2.0	4.1	7.2
Gr_4	2.5	11	22	44	76
Gr_5	1.0	4.2	8.3	17	29
Li_1	0.38	1.6	3.3	6.6	11
Li_2	1.4	6.0	12	24	42
Li_3	0.09	0.38	0.76	1.5	2.7
Li_4	3.5	15	30	60	105
Li_5	4.2	18	36	72	125
NB_1	1.0	4.4	8.7	17	31
NB_2	2.0	8.8	18	35	61
NB_3	1.9	8.0	16	32	56
NB_4	4.0	17	34	68	119
NH_1	1.0	4.2	8.5	17	30
NH_2	0.86	3.7	7.4	15	26
NH_3	0.57	2.5	4.9	9.8	17
Ov_1	0.12	0.52	1.0	2.1	3.6
Ov_2	0.07	0.29	0.59	1.2	2.1
Ov_3	0.94	4.0	8.0	16	28
Ov_4	0.37	1.6	3.2	6.4	11

Location	PFAS exposure at different consumption frequencies (in ng PEQ/kg body weight)				
	1 egg per month	Number of eggs per week			
		1	2	4	7
Ov_5	2.8	12	24	48	84
Ut_1	3.7	16	31	63	110
Ut_2	3.6	16	31	62	109
Ut_3	6.6	28	57	113	198
Ut_4	0.37	1.6	3.2	6.3	11
Ut_5	0.06	0.27	0.53	1.1	1.9
Ut_6	1.9	8.0	16	32	56
Ut_7	0.21	0.91	1.8	3.7	6.4
Ut_8	2.0	8.8	18	35	62
Ze_1	1.3	5.7	11	23	40
Ze_2	1.7	7.4	15	29	51
Ze_3	0.95	4.0	8.1	16	29
Ze_4	6.0	26	51	102	179
Ze_5	5.5	24	47	94	165
SH_1	3.0	13	26	53	93
SH_2	0.04	0.15	0.30	0.6	1.1
SH_3	1.2	4.9	9.8	20	34
SH_4	0.98	4.2	8.4	17	29
SH_5	0.56	2.4	4.8	9.5	17

Dr: Drenthe; Fl: Flevoland; Fr: Friesland; Ge: Gelderland; Gr: Groningen; Li: Limburg; NB; North Brabant; ng: nanogram; NH: North Holland; Ov: Overijssel; PEQ: PFOA-equivalents; PFAS: per- and polyfluoroalkyl substances; SH: South Holland; Ut: Utrecht; Ze: Zeeland

Appendix F Summed concentration of the EFSA-4 in home-produced eggs per location

Location	Summed concentration of EFSA-4 (in ng per gram)[a,b,c,d]	Location	Summed concentration of EFSA-4 (in ng per gram)[a,b,c,d]
Dr_1	0.0	Ze_1	2.0
Ov_1	0.07	SH_4	2.1
Li_3	0.11	SH_3	2.2
SH_2	0.11	NB_3	2.6
Fr_5	0.13	Fl_4	2.6
Ov_2	0.14	Ge_5	2.6
Ut_5	0.14	Fl_3	2.7
Gr_2	0.29	Ut_8	2.8
Ge_2	0.31	Fr_1	2.9
Fl_1	0.38	Dr_4	3.0
Ut_4	0.40	Fl_2	3.1
Ge_3	0.43	NB_2	3.2
Gr_3	0.46	Ze_2	3.2
Ut_7	0.46	Gr_1	3.3
Dr_3	0.51	NB_4	3.3
Dr_5	0.51	Li_4	3.4
Li_1	0.54	Ut_2	3.8
Ov_4	0.54	Fr_3	3.9
Fr_4	0.62	Ge_4	4.3
NH_3	0.74	Ut_1	4.5
NH_1	0.91	Ov_5	4.7
Dr_2	1.1	Fl_5	4.8
Ov_3	1.1	Gr_4	5.5
Ut_6	1.1	Fr_2	5.7
SH_5	1.1	SH_1	5.8
Ze_3	1.3	Li_5	8.1
NH_2	1.4	Ut_3	11
Gr_5	1.8	Ze_4	12
NB_1	1.8	Ze_5	14
Li_2	1.9	Ge_1	18

Dr: Drenthe; Fl: Flevoland; Fr: Friesland; Ge: Gelderland; Gr: Groningen; Li: Limburg; NB; North Brabant; ng: nanogram; NH: North Holland; Ov: Overijssel; PFAS: per- and polyfluoroalkyl substances; SH: South Holland; Ut: Utrecht; Ze: Zeeland

[a] EFSA-4: PFOA, PFNA, PFHxS, and PFOS. For the names of these four PFAS, see Table 1 in section 2.2.

[b] Summed concentrations were calculated by adding up the concentrations of the EFSA-4, assuming that the substances are equipotent and that their effects are additive (EFSA. 2020).

[c] Summed concentrations are presented in ascending order.

[d] The maximum level for the sum of the EFSA-4 in eggs is 1.7 ng per gram (Regulation (EU) 2023/915; see section 6.2).

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