German Federal Institute for Risk Assessment

Opinion 043/2025

doi https://doi.org/10.17590/20260709-091655-0

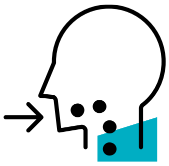
6 October 2025

Despite less PFAS in free-range and barn eggs, eggs and egg products still contribute to overall exposure

In brief

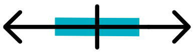
- Per- and polyfluoroalkyl substances (PFAS) are a large group of chemicals used in numerous industrial processes and products. PFAS are hardly degradable and thus remain in the environment for a long time and enter into the food chain. Based on occurrence data from food monitoring in 2024, the German Federal Institute for Risk Assessment (BfR) has estimated the amounts of the four PFAS, perfluorooctanesulfonic acid (PFOS), perfluoroundecanoic acid (PFOA), perfluorononanoic acid (PFNA) and perfluorohexanesulfonic acid (PFHxS), ingested via chicken eggs. A distinction was made between eggs from free-range, barn and organic production.
- The results show that none of the samples exceeds the legally established maximum level for the sum of the four PFAS. The maximum levels for the four individual compounds are also not exceeded. A comparison of the current concentrations with those found in previous studies shows a downward trend over the years in the average PFAS concentrations in eggs from all production types for the sum of the four PFAS. Nevertheless, eating chicken eggs can make a relevant contribution to overall exposure to PFAS. The highest concentrations were found in eggs from organic production and free-range hens. Eggs from barn-raised hens had substantially lower PFAS concentrations.
- The estimated intake of PFAS through the consumption of chicken eggs does not exceed the health-based guidance value (HBGV). Health impairments solely from the consumption of eggs are therefore not to be expected. However, PFAS are also ingested via a variety of other foods. When considering the total intake of PFAS via food, the health-based guidance value (HBGV) may be exceeded (see BfR Opinion No. 020/2021 issued 28 June 2021). Exposure above the tolerable weekly intake (TWI) in parts of the population is a cause for health concern (EFSA 2020).

How do the four PFAS under consideration enter the body?



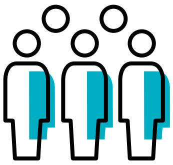
The intake of PFAS from chicken eggs occurs **orally** through meals.

Is there a health-based guidance value?



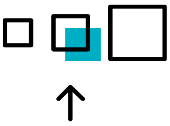
The health-based **guidance value** (HBGV) for the tolerable weekly intake (TWI) for the sum of PFOA, PFOS, PFNA and PFHxS is 4.4 nanograms (ng) per kilogram of body weight. No impairment is expected from lifelong intake of this amount.

Is there a health risk?



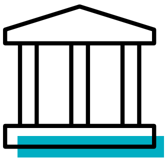
The estimated intake of the four PFAS mentioned above through the consumption of chicken eggs does not exceed the health-based guidance value (HBGV). Consumers also ingest these substances through other food. When considering the total food-based intake of the four PFAS mentioned above, the health-based guidance value (HBGV) may be exceeded. Exposure above the TWI in parts of the population is cause for health concerns.

What ist the quality of the data?



The quality of the data is **moderate,** as although the number of samples examined has increased substantially, it is still too small to make representative statements about the overall situation in Germany, and regional differences are not fully reflected. Despite vast improvements in analysis in recent years which have made data evaluation more sensitive, the concentrations of the four PFAS mentioned are below the limit of quantification (LOQ) in approximately 75% of the samples taken.

How can the health risk from PFAS in chicken eggs be reduced?



Due to PFAS' ubiquitous presence in the environment, **the government** can only influence their intake via food such as eggs by taking measures to reduce the entry of PFAS into the food chain. The lower PFAS concentrations in the food monitoring samples from 2024 compared to older studies indicate the success of these measures.

Due to PFAS' ubiquitous presence in the environment, **producers** can only influence their intake via food such as eggs by taking measures to reduce the entry of PFAS into the food chain. This includes, for example, quality assurance measures for animal feed and drinking water as well as for finished products. In organic and free-range farming, however, the main route via which PFAS enter into the soil can only be influenced to a very limited extent.

Consumers have little influence over their exposure to PFAS as ubiquitous environmental contaminants. The prevalence of PFAS in food can mainly be influenced by avoiding and sealing off sources of entry into the environment. In the context of food safety and healthy nutrition, consumers are advised to eat a varied and balanced diet.

Subject of the assessment

The German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) tasked the German Federal Institute for Risk Assessment (BfR) with conducting a health risk assessment of data on the occurrence of per- and polyfluoroalkyl substances (PFAS) in chicken eggs based on food monitoring data from 2024. The goal was to make the evaluation as differentiated as possible with respect to production types respectively farming methods.

Results

The results of the evaluation can be summarised as follows:

2.1 Occurrence data from the 2024 monitoring

In the available data set on the occurrence of per- and polyfluoroalkyl substances (PFAS) in chicken eggs from the 2024 monitoring, the proportion of samples with concentrations above the limit of quantification (LOQ) for the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) is 24 % in total, with major differences between the types of farming. The mean concentration of the sum of the four PFAS in eggs from organic production is 0.09 µg/kg (lower bound (LB) approach) and 0.07 µg/kg (LB) for free-range eggs, while the average concentration of the sum of the four PFAS in barn eggs is many times lower (0.001 µg/kg, LB).

None of the samples with quantifiable PFAS concentrations exceeded the maximum level of 1.7 µg/kg for the sum of the four PFAS compounds specified in Regulation (EU) 2023/915. The corresponding maximum levels for the four individual compounds were also not exceeded.

2.1.1 Exposure assessment

Based on the occurrence data from the monitoring (2024), the BfR has conducted an exposure assessment for the four PFAS (PFOS, PFOA, PFNA and PFHxS) named in Regulation (EU) 2023/915 through the consumption of chicken eggs from different farming systems (barn, free-range and organic production) for children and adults. Three hypothetical consumption scenarios for eggs were used, with the assumption that only chicken eggs from one of three farming systems are consumed (only barn, free-range or organic production). For the risk characterisation, the tolerable weekly intake (TWI) of 4.4 nanograms (ng) per kilogram (kg) of body weight (bw) per week for the sum of the four PFAS mentioned above, as derived by the European Food Safety Authority (EFSA), was used as a basis (EFSA 2020).

a) For adults in Germany, long-term exposure to the sum of the four EFSA PFAS through the consumption of chicken eggs with average concentrations, using the LB, ranges from 0.002 to 0.17 ng/kg bw per week (50th percentile) to 0.005 to 0.54 ng/kg bw per week (95th percentile), depending on the consumption scenario considered. This means that the estimated exposure to the four PFAS is below the TWI of 4.4 ng/kg bw per week and reaches 0.05–4% (50th percentile) or 0.1–11 % (95th percentile) of the TWI. When comparing the three scenarios, long-term PFAS exposure from the consumption of free-range and organic eggs is highest (8–11 % of the TWI in the 95th percentile).

b) In children, long-term exposure to PFAS through the consumption of chicken eggs exceeds that of adults by about three to five times in all scenarios. Depending on the consumption scenario considered, the long-term exposure of children in Germany to the sum of the four PFAS through the consumption of chicken eggs ranges from 0.01–0.57 ng/kg BW per week (50th percentile) to 0.02–2.00 ng/kg bw per week (95th percentile). The exposure corresponds to 0.2–13 % (50th percentile) and 0.5–45 % (95th percentile) of the TWI, respectively. As with adults, when comparing the three scenarios, the long-term PFAS exposure of children is highest when consuming free-range and organic eggs (33–45 % of the TWI in the 95th percentile).

2.2 Conclusion

Due to the ubiquitous prevalence of PFAS in the environment and their prevalence in numerous consumer products and foods, overall exposure is composed of many different sources.

The exposure assessment based on three hypothetical scenarios shows that the consumption of chicken eggs – especially free-range and organic eggs – can make a substantial contribution to overall exposure to PFAS. However, if eggs are sourced exclusively from one farming system, these results can be interpreted as realistic lower and upper estimates of actual exposure.

Compared to current concentrations, though, the average PFAS concentrations in eggs from all production types have declined over the years. The average PFAS concentrations in chicken eggs in the 2007–2020 data set are 0.36 µg/kg (95th percentile: 1.6 µg/kg), in the years 2018–2022 at 0.29 µg/kg (95th percentile: 1.00 µg/kg) and in the 2024 monitoring at 0.06 µg/kg (95th percentile: 0.42 µg/kg). This corresponds to a four- to six-fold decrease in PFAS concentrations in chicken eggs. The decline in PFAS concentrations is most pronounced in recent years (2018–2022 compared to 2024). As PFAS concentrations in chicken eggs, especially in eggs from barn and free-range farming, are lower than in 2018–2022, exposure for adults and children is currently lower. While the exposure assessment for children based on the 2018–2022 occurrence data exceeds the TWI (scenario 2: free-range; 95th percentile, LB), exposure based on monitoring data from 2024 (LB) reaches a maximum of 45 % of the TWI (scenario 3, 95th percentile).

Rationale

3.1 Risk assessment

3.1.1 Hazard identification and hazard characterisation

PFAS are a large group of industrial chemicals that are used in numerous industrial processes and consumer products due to their special technical properties (e.g. water, grease and dirt repellent properties). PFAS are difficult to degrade and therefore remain in the environment for a long time and can also be detected in the food chain and in humans. After intake via food, drinking water or other sources, some PFAS can accumulate in the human body, meaning that even low or short-term intake of these substances can contribute to higher concentrations in the body in the long term.

In 2020, EFSA assessed various PFAS, including both perfluoroalkylcarboxylic acids and perfluoroalkylsulfonic acids. Due to similar hazard characterisations in terms of effects in animals, toxicokinetics, and observed concentrations in human blood, EFSA focused its risk assessment on the sum of the four PFAS: PFOS, PFOA, PFNA and PFHxS (EFSA PFAS).

EFSA identified the correlations observed in epidemiological studies between PFAS concentrations in blood and reduced concentrations of vaccine antibodies in children as critical effect. On this basis, EFSA derived a TWI of 4.4 ng/kg bw/week for the four EFSA PFAS (EFSA 2020).

Detailed information on hazard identification and hazard characterisation can be found in the BfR opinion "PFAS in food: BfR confirms critical exposure to industrial chemicals" (BfR 2021). The risk assessment in this opinion focuses on the EFSA PFAS for which the health-based guidance value (HBGV) was derived.

3.1.2 Hazard characterisation

3.1.2.1 Occurrence data

To estimate exposure, a data set provided by the German Federal Office of Consumer Protection and Food Safety (BVL) was used, which contains data from monitoring in accordance with Sections 50-52 of the German Food and Feed Code (LFGB) from 2024. In total, the data set consists of 762 measurements of 17 different PFAS compounds in 69 egg samples. Measurements where the type of farming could not be clearly assigned to one of the three groups "barn-raised", "free-range" and "product according to the Organic Regulation (EC)" were excluded. This affected one sample from aviary farming. Furthermore, one sample that was not tested for all of the four PFAS mentioned above was excluded. A total of 268 measurements of the four PFAS from 67 samples were thus included in the exposure assessment. In addition, the current occurrence data (2024) was compared with the food monitoring data from 2007 to 2020 (N = 26 samples) (BfR 2021) and with occurrence data from 2018–2022 submitted by the German federal states ("Laender") (N = 181). It should be noted that there may be differences in data collection between the data sets, as they partly contain data from different monitoring programmes.

For further evaluation, the sum of the four PFAS was calculated. Values below the limit of detection (LOD) or limit of quantification (LOQ) were handled using two different approaches. In the lower bound (LB) approach, all values below the LOD or LOQ were replaced by 0. The use of this approach can lead to an underestimation of the concentrations and thus of the resulting exposure. In the "upper bound" (UB) approach, the following procedure was used: if at least one of the four PFAS values in the sample could be determined, only the determined values were added up and the others were considered as 0, as in the LB approach. If all values were below the limit of quantification, the value of the highest limit of quantification was assigned as the sum for the four substances. This procedure avoids the limits of quantification being added up multiple times in the case of several censored values. This is necessary because, although the limits of quantification have become lower over the years since the BfR opinion in 2021 (Annex **Fehler! Verweisquelle konnte nicht gefunden werden.** ,Table13), in some cases they are only in the range of the respective maximum content specified by law in Regulation (EU) 2023/915. The results of the two approaches reflect the range within which the actual concentrations are highly likely to be located.

PFAS concentrations based on data from monitoring in 2024

The levels of the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) in chicken eggs using the LB and UB approaches are shown in**Fehler! Verweisquelle konnte nicht gefunden werden.** andTable2 . Almost 60 % of the samples come from free-range chicken eggs, 16 % from barn eggs and the rest from products in accordance with the Organic Regulation.

A comparison with market data (GfK 2016) collected for the BfR-MEAL study in 2016 shows that free-range and organic eggs are overrepresented in the present data set. There, the market share of free-range eggs was 25.5 %, that of barn eggs 57.1 % and that of organic eggs 11.4 %. The distribution of actual production volumes for eggs in recent years is also in the range of the latter figures (Statista 2023).

The proportion of concentrations above the limit of quantification (LOQ) for the sum of the four PFAS is 24 %. There are clear differences between the types of farming. In eggs from barn-raised hens, 9 % of the concentrations were above the limit of quantification (LOQ), while in eggs from free-range and organic production, 20 % and 44 % of the concentrations were above the limit of quantification (LOQ), respectively.

All concentrations measured in the 2024 monitoring were below the legally established maximum concentration (Regulation (EU) 2023/915) of 1.7 µg/kg for the sum of the four PFAS in egg. The corresponding maximum concentrations for the four individual compounds were also not exceeded.

Statistically robust differences in the levels of the sum of the four PFAS are evident for the 95th percentile between eggs from barn-raised hens compared to eggs from free-range or organic production. The mean concentration of the sum of the four PFAS in eggs from organic production is 0.09 µg/kg (LB) and for eggs from free-range production 0.07 µg/kg (LB). These concentrations are many times higher than the mean concentration for eggs from barn-raised hens (0.001 µg/kg, LB). The differences in PFAS levels (sum of four PFAS, mean value, LB) between barn eggs and free-range or organic eggs are statistically significant.

Similar differences in terms of farming methods can be seen in the 95th percentile of concentrations. The concentration of the sum of the four PFAS in free-range eggs is higher at 0.36 µg/kg than for barn eggs (0.01 µg/kg), while the concentration in products in accordance with the Organic Regulation (0.49 µg/kg) is even higher. Here, the differences in the occurrence data for free-range eggs or products in accordance with the Organic Regulation are also considerably different from the concentrations in barn eggs[1] .

The differences in PFAS concentrations in chicken eggs between the different types of hen housing show that it makes sense to take a differentiated view with regard to the type of farming.

[1] The confidence intervals were determined using a non-parametric bootstrap method.

Table1 : Overview of the levels of the sum of four PFAS (PFOS, PFOA, PFNA and PFHxS) in chicken eggs (in µg/kg), using the lower bound (LB) approach, broken down by farming method. For comparison, the respective mean values (MV) and the 95th percentile (P95) from three survey periods (2007–2020, 2018–2022, 2024) are shown based on data provided by the BVL from the regional food surveillance authorities of the German federal states.

	2007-2020 [a]				2018–2022				2024			
Group	Valid N	Concentrations above LOQ in %	PFAS concentration, LB in µg/kg		Valid N	Concentration above LOQ in %	PFAS concentration, LB in µg/kg		Valid N	Concentration above LOQ in %	PFAS concentration[d] LB in µg/kg	
			MV	P95			MV (95 % CI)	P95 (95 % CI)			MV (95 % CI)	P95 (95 % CI)
All	26	23	0.36	1.6	181	31	0.29 (0.12-0.55)	1.0 (0.40-2.30)	68[c]	24	0.06 (0.03-0.1)	0.42 (0.22-0.57)
Barn-raised	n/a	n/a	n/a	n/a	55	9	0.05 (0[b] -0.11)	0.20 (0[b] -1.06)	11	9	0.001 (0[b] -0.003)	0.01 (0[b] -0.01)
Free-range	n/a	n/a	n/a	n/a	93	41	0.49 (0.16-0.97)	1.70 (0.50-6.99)	40	20	0.07 (0.02-0.12)	0.36 (0.23-0.62)
Product in accordance with Organic Regulation (EC)	n/a	n/a	n/a	n/a	33	42	0.10 (0.05-0.16)	0.37 (0.24-0.65)	16	44	0.09 (0.02-0.18)	0.49 (0.08-0.57)

[a] Based on the BfR opinion 2021 (BfR 2021) , in which no differentiation was made between PFAS concentrations in chicken eggs from different farming systems (n/a).

[b] Due to the non-parametric method and the small number of values above the limit of quantification (LOQ), the lower limit of the confidence interval (CI) is equal to 0.

[c]One sample was taken from eggs from aviary farming and is not taken into account further.

[d]Maximum concentration according to Regulation (EU) 2023/915 sum of four PFAS (PFOA, PFOS, PFNA, PFHxS) in eggs: 1.7 µg/kg.

Table2 : Overview of the levels of the sum of four PFAS (PFOS, PFOA, PFNA and PFHxS) in chicken eggs (in µg/kg), using the upper bound (UB) approach, broken down by type of farming. For comparison, the respective mean values (MV) and the 95th percentile (P95) from three survey periods (2007–2020, 2018–2022, 2024) are shown based on data provided by the BVL from the regional authorities of the German federal states.

	2007-2020[a]				**2018–2022**				**2024**			
Group	**Valid N**	**Concentrations above LOQ in %**	**PFAS concentration, UB in µg/kg**		**Valid N**	**Concentration above LOQ in %**	**PFAS concentration, UB in µg/kg**		**Valid N**	**Concentration above LOQ in %**	**PFAS concentration**[c] **, UB in µg/kg**	
			MV	**P95**			**MV (95 % CI)**	**P95 (95 % CI)**			**MV (95 % CI)**	**P95 (95 % CI)**
All	26	23	0.86	n/a	181	31	0.64 (0.47-0.88)	2.00 (1.00-2.30)	68[b]	24	0.21 (0.17-0.24)	0.42 (0.3-0.57)
Barn-raised	n/a	n/a	n/a	n/a	55	9	0.57 (0.41-0.74)	2.00 (1.00-2.00)	11	9	0.17 (0.10-0.24)	0.30 (0.25-0.30)
Free-range	n/a	n/a	n/a	n/a	93	41	0.78 (0.44–1.25)	1.70 (1.00-6.99)	40	20	0.24 (0.20-0.28)	0.36 (0.30-0.62)
Product in accordance with Organic Regulation (EC)	n/a	n/a	n/a	n/a	33	42	0.36 (0.22–0.53)	1.00 (1.00-2.00)	16	44	0.16 (0.10-0.24)	0.49 (0.20-0.57)

Based on the BfR opinion 2021 (BfR 2021) , in which no differentiation was made between PFAS concentrations in chicken eggs from different types of farming (n/a).

[b] One sample was taken from eggs from aviary farming and is not taken into account further.

[c] Maximum concentration according to Regulation (EU) 2023/915 for the sum of four PFAS (PFOA, PFOS, PFNA, PFHxS) in eggs: 1.7 µg/kg.

Using the UB approach, there are hardly any visible differences between the concentrations of the sum of the four PFAS in eggs from the respective types of hen husbandry (Table2). The sum of PFAS concentration of organic eggs is slightly lower at 0.16 µg/kg compared to 0.24 µg/kg for free-range eggs and 0.17 µg/kg for barn eggs. The slight differences in concentrations using the UB approach can be explained by the similar detection and determination limits in combination with the high proportion of values below the LOQ. In this case, samples with concentrations below the LOQ are given the same value regardless of the type of farming, which reduces the differences between the types of farming.

Comparison of PFAS concentrations in chicken eggs with data sets from previous studies

It is possible to compare the data on PFAS concentrations in chicken eggs from the 2024 monitoring with data from a dataset provided by the German federal states for the years 2018–2022 and food monitoring data from the years 2007–2020 (BfR 2021) .

Although the 2021 evaluation did not distinguish between different types of farming, all samples came from barn and free-range farming. Compared with current concentrations, the average PFAS concentrations for all types of production have declined over the years. For example, the average PFAS concentrations in chicken eggs in the 2007–2020 data set are 0.36 µg/kg (95th percentile: 1.6 µg/kg), in the years 2018–2022 at 0.29 µg/kg (95th percentile: 1.00 µg/kg) and in the 2024 monitoring at 0.06 µg/kg (95th percentile: 0.42 µg/kg). This corresponds to a four- to six-fold decrease in PFAS concentrations in chicken eggs. The decline in PFAS concentrations is most pronounced in recent years (2018–2022 compared to 2024). The lower PFAS concentrations may be related to refinements in the limit of quantification (LOQ) (Annex **Fehler! Verweisquelle konnte nicht gefunden werden.**,Table13) as well as to differences in data collection and to the establishment of maximum levels for PFAS in chicken eggs that came into force in 2023 (Regulation (EU) 2023/915).

3.1.2.2 Consumption data

The National Consumption Study II (NVS II) reflects food consumption among adults, while the Children's Nutrition Study for Recording Food Consumption, or "KiESEL" study for short, reflects food consumption among children.

Both consumption studies are briefly explained in the following: The NVS II of the Max Rubner Institute (MRI) provides the foundational data for egg consumption by adults. The NVS II is currently the most up-to-date representative study on consumption by the population in Germany. The study, in which around 20,000 people aged between 14 and 80 were surveyed about their eating habits using three different methods (dietary history, 24-hour recall and weighing protocol), took place throughout Germany between 2005 and 2006 (MRI 2008a, b).

The consumption analyses used here (Table3) are based on data from the NVS II dietary history interviews, which were collected using the DISHES 05 programme. Using the "Dietary History" method, 15,371 respondents were surveyed and their usual consumption over the previous four weeks was recorded retrospectively. It provides estimates for the long-term intake of substances when food is grouped into categories or food that is consumed regularly is considered. For eggs, it is assumed that the dietary history interviews provide a good description of long-term consumption. The consumption data analyses were carried out at the BfR as part of the "LExUKon" project (Blume et al. 2010) funded by the BMUV (now called BMUKN). To calculate consumption quantities, all recorded recipes/dishes and almost all composite foods were broken down into their unprocessed individual components and, where necessary, processing factors were taken into account. This means that all relevant consumption quantities were included. Most of the recipes are based on standard recipes and therefore do not take into account variations in preparation/production and the resulting consumption amounts.

The KiESEL study serves as the data basis for the consumption of chicken eggs by children. The study was linked as a module to the RKI's "Study on the Health of Children and Adolescents in Germany" ("KiGGS Wave 2"). A total of 1,104 children aged between 6 months and 5 years took part in KiESEL. Based on an interview, the parents or guardians completed a questionnaire on general nutrition, nutrition in the first year of life and a food propensity questionnaire on foods that are rarely consumed. Of these, 1,008 children and their parents also took part in the nutrition survey using a weighing/estimation protocol. The children's food consumption was documented in a weighing protocol for three consecutive days and in a 1-day weighing protocol on an independent day. In addition, out-of-home consumption (e.g. in childcare facilities) was recorded using a reduced estimation protocol (Nowak et al. 2022).

For the exposure assessment, the total consumption of chicken eggs, including dishes made from chicken eggs (but not portions in industrially produced cakes, etc.), was taken into account. Since children aged 6 and 14 are between the toddlers and adults (aged 14-65+) in the KiESEL study in terms of their exposure relative to their body weight, no separate exposure assessment was carried out and it can be assumed that this is within the range of the age groups presented here.

Consumption differences according to farming method

Due to the specific focus of the consumption survey methodology on exposure issues, the consumption data collected by the BfR from KiESEL evaluations at the level of recorded individual consumption events allow us to determine whether the consumption of chicken eggs differs depending on farming method and whether eggs from organic or conventional farming were consumed. For each food, an additional question was asked as to whether it was from organic or conventional farming. As this question is not specifically formulated for eggs, it is not possible to differentiate between other farming methods. However, this information was recorded in the free text field for describing the food consumed by at least some of the test subjects and was therefore evaluated additionally. Two different evaluations were thus carried out:

- Differences depending on whether the "organic" column was ticked in the diary or not
- Evaluation of the free text field for food information, whether the type of farming was specified there or not

The first method has the advantage that information is available for each consumption event. However, it is not possible to assign the data precisely to the categories of occurrence data (barn/free-range). The information from the free text field, on the other hand, allows assignment to all farming methods also shown in the occurrence data. However, as these were not systematically queried, the free text designation does not contain any information on the farming method for a large proportion of egg consumption events (60 %).

This comparison is shown in Table 4. Here, the consumption of chicken eggs by all children was grouped according to farming method or the "organic" field that was ticked. A total of 313 children consumed eggs or dishes containing eggs on the four days of the protocol. If a child had several consumption events that could be assigned to different farming methods, these were counted once in each of the corresponding groups, so that the total number of entries in Table 4 is more than 313. 25% of the children who consumed eggs also consumed organic eggs at least once. Of the consumption events for which information on the type of farming was also available from the free text field, as many as 31 % consumed eggs from organic farming at least once, 47 % of consumption events can be attributed to barn farming and 22 % to free-range farming.

There were no considerable differences in consumption amounts between the different types of farming: although the median consumption in the "free-range" group was higher than in the "barn" group (0.68 g/kg bw per day) and the "product in accordance with the Organic Regulation" group (0.58 g/kg bw per day), but as the confidence intervals overlap, this difference is not statistically significant. In the case of heavy consumption (represented by the 95th percentile), the consumption of eggs from barn-raised hens (1.23 g/kg bwper day) is lower than that of free-range eggs (2.03 g/kg bw per day) and organic eggs (2.48 g/kg bw per day). Here, too, the differences are not statistically significant due to the overlap of the confidence intervals. The group of consumption events for which it was not possible to assign the type of farming via the free text field tended to show the highest consumption amounts, but these were also not significantly different from all types of farming.

The evaluation according to the "organic" column ticked in the diary also shows only minor differences: the medians are 0.74 g/kg bw per day ("yes") and 0.85 g/kg bw per day ("no") with overlapping confidence intervals. This is also the case in the 95th percentile, which is 3.37 g/kg bw per day for "Yes" and 2.67 g/kg bw per day for "No".

The consumption of chicken eggs from conventional farming tends to be lower than the consumption of eggs from organic or free-range farming. However, the differences are not significant. Due to this and the fact that the type of farming could not be assigned for most consumption events based on the free text field, no distinction is made between types of farming in the following evaluations on the consumption side. Regardless of this, it is not possible to do so for adults due to a lack of differentiation in the NVS II.

Table3 : Long-term consumption of chicken eggs by adults based on the NVS-II study: The mean (MV), median (P50) and 95th percentile (P95) are shown for all adults and differentiated by gender.

Adults	Number of consumers/all respondents	Consumption in g/kg body weight per day		
		MV	**P50**	**P95**
Total	15,250/15,371	0.314	0.253	0.787
Male	7,558/7,613	0.325	0.257	0.848
Female	7,692/7,758	0.302	0.249	0.743

Table4: Long-term consumption of chicken eggs by children based on the KiESEL study, differentiated by production method and type of chicken farming. The mean (MV), median (P50) and 95th percentile (P95) are shown. Children with consumption events in several groups appear in all applicable groups according to their respective consumption. This results in a higher total number of consumption events across all farming systems than the number of children who consumed eggs.

Children		Valid N	Consumption in g/kg bw per day		
			MV (95 % CI[a])	**P50 (95 % CI[a])**	**P95 (95 % CI[a])**
Total		313[b]	1.14 (1.04- 1.25)	0.88 (0.78- 0.94)	3.11 (2.53- 4.27)
Type of farming according to free text field	No information	212	1.14 (1.03–1.27)	0.89 (0.82-0.94)	3.37 (2.57-4.00)
	Barn-raised	66	0.76 (0.66-0.87)	0.68 (0.66-0.91)	1.23 (0.99-2.06)
	Free-range	31	0.99 (0.86-1.13)	0.89 (0.67-1.04)	2.03 (1.43-2.50)
	Product in accordance with Organic Regulation (EC)	44	0.83 (0.65-1.04)	0.58 (0.49-0.74)	2.48 (1.32-3.05)
Biologically crossed	Yes	87	1.02 (0.85-1.20)	0.74 (0.65-0.80)	3.37 (2.01-3.37)
	No	267	1.02 (0.92-1.13)	0.85 (0.78-0.91)	2.67 (1.93-3.28)

[a] Confidence intervals (CI) were determined using a non-parametric bootstrap method.

[b] The total number of participants who consumed eggs varies, because children who consumed both organic eggs and eggs from other farming methods were counted in both groups.

3.1.2.3 Exposure

Three scenarios are considered to estimate exposure to PFAS through the consumption of chicken eggs. In each of these three scenarios, it is assumed that total egg consumption corresponds to the consumption of eggs from only one type of farming (barn, free-range or organic). This represents the maximum possible range of exposure from the consumption of chicken eggs from different farming systems. In reality, not all consumers consume chicken eggs from only one farming system, as consumers have little control over industrially produced products containing chicken eggs, among other things.

The exposure assessment was calculated by multiplying long-term consumption, taking into account individual body weight (determined as the mean value of all survey days in the case of KiESEL or direct survey in NVS-II-DISHES), by the respective mean concentration of the sum of the four PFAS in chicken eggs from the corresponding farming systems. The median and 95th percentile of the resulting distribution were then presented. Possible differences by gender and, in the case of the KiESEL study, by age group were also presented. Only participants in the consumption studies who had consumed chicken eggs during the observation period were included in the exposure assessments.

The following sections only consider scenarios with concentrations based on the LB approach. Since a high percentage of PFAS concentrations are below the LOQ and the LOQ still tend to be high, it can be assumed that the estimates in the UB approach deviate considerably more upwards than in the LB approach downwards. Consequently, the exposure assessment using the LB approach leads to a more realistic assessment of exposure to PFAS compared to the UB approach (BfR 2021; EFSA 2020). The corresponding tables of exposure assessments based on concentrations using the UB approach can be found in Appendix **Fehler! Verweisquelle konnte nicht gefunden werden.**.

The estimated long-term exposure for **adults** in Germany to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of chicken eggs is shown inTable5 for barn eggs (scenario 1), in

Table6 for free-range eggs (scenario 2) and inTable7 for organic eggs (scenario 3). Due to the differences in concentration, scenario 1: barn-raised shows the lowest exposure to PFAS with a long-term exposure of 0.002 ng/kg bw per week (50th percentile). In scenario 2: free-range farming, long-term exposure to PFAS through the consumption of chicken eggs was 0.12 ng/kg bw per week (50th percentile), and in scenario 3: organic production, long-term exposure was 0.16 ng/kg bw per week (50th percentile). Due to the higher concentrations of PFAS in eggs from free-range and organic production, the corresponding estimated exposures in scenarios 2 and 3 are also higher than the exposure in scenario 1. The differences in exposure between the scenarios are also evident in the 95th percentile. When comparing the estimated long-term exposure of both sexes, there are hardly any differences.

In a temporal comparison, analogous to the occurrence data, the PFAS exposure of adults for all production types is lower at 0.64 ng/kg bw (survey period 2007–2020), ranging from 0.51 ng/kg bw (survey period 2018–2022) to 0.11 ng/kg bw (survey period 2024, Appendix 5.3 ,Table 20). When comparing the estimated long-term exposure to PFAS based on occurrence data from the 2018–2022 survey period with that based on the 2024 monitoring data, taking into account the type of production for eggs from barn and free-range farming, the more recent data show lower exposures (50th percentile), while PFAS exposure from the consumption of eggs from organic production is comparable (Table5,

Table6 andTable7).

Table5: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the lower bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg body weight per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	15,250	0.11	0.09	0.28	0.002	0.002	0.005
Male	7,558	0.11	0.09	0.30	0.002	0.002	0.005
Female	7,692	0.11	0.09	0.26	0.002	0.002	0.005

Table6: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the lower bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	15,250	1.08	0.87	2.72	0.14	0.12	0.36
Male	7,558	1.12	0.89	2.93	0.15	0.12	0.39
Female	7,692	1.04	0.86	2.57	0.14	0.11	0.34

Table7: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of organic chicken eggs using the lower bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	15,250	0.22	0.18	0.56	0.20	0.16	0.51
Male	7,558	0.23	0.18	0.60	0.21	0.17	0.54
Female	7,692	0.21	0.18	0.53	0.19	0.16	0.48

The estimated long-term exposure for **children** to the sum of PFOS, PFOA PFNA and PFHxS through the consumption of chicken eggs is shown inTable8 for barn eggs (scenario 1), inTable9 for free-range eggs (scenario 2) andTable10 for organic eggs (scenario 3). As with adults, long-term exposure to PFAS through the consumption of chicken eggs is lowest in scenario 1: barn eggs (0.01 ng/kg bw per week, 50th percentile) and highest in scenario 2: free-range eggs (0.41 ng/kg bw per week, 50th percentile) and scenario 3: organic eggs (0.57 ng/kg bw per week, 50th percentile). percentile) and scenario 3: organic production (0.57 ng/kg bw per week, 50th percentile). The differences in exposure between the scenarios are also evident in the 95th percentile and are based exclusively on the differences in the concentrations of PFAS in the eggs from the respective farming systems.

Differences between age groups and genders are examined below using scenario 3: organic production. In contrast to adults, there are differences in estimated exposure between genders in children. Girls have higher exposure than boys, which is particularly evident in the 95th percentile. In scenario 3: organic production, the estimated PFAS exposure is 2.74 ng/kg bw per week for girls and 1.56 ng/kg bw per week for boys.

The age group of 0.5 - < 1-year-old children is not listed because the number of children who consume chicken eggs in this age group is too small for a reliable evaluation (n = 1 after weighting). Of the three age groups considered, children aged 1 - < 2 years of age have the highest PFAS exposure from the consumption of chicken eggs at 0.7 ng/kg bw per week (50th percentile), followed by children aged 2 - < 3 years with an exposure of 0.65 ng/kg bw per week (50th percentile). In the group of children over 3 years of age, long-term exposure to PFAS through the consumption of eggs is 0.54 ng/kg bw per week (50th percentile). This reflects the decrease in consumption relative to body weight in children as they get older. This trend is not clearly evident in the 95th percentile, which can be explained by the comparatively small sample sizes in the younger age groups.

When comparing the estimated long-term exposure to PFAS based on occurrence data from the 2018-2022 survey period with that based on the 2024 monitoring data, taking into account the production type for eggs from barn and free-range farming, the more recent data show lower exposures (50th percentile), while PFAS exposure from the consumption of eggs from organic production is comparable (Table8 Table10).

Table8 : Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the lower bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Children	Number of consumers *	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	316	0.40	0.31	1.10	0.01	0.01	0.02
Male	153	0.37	0.28	0.86	0.01	0.01	0.02
Female	164	0.43	0.32	1.51	0.01	0.01	0.03
1-< 2 years	38	0.48	0.38	1.48	0.01	0.01	0.03
2-< 3 years	58	0.37	0.36	0.74	0.01	0.01	0.01
⩾ 3 years	219	0.40	0.29	1.11	0.01	0.01	0.02

*Due to sample weightings, rounding is prevalent and may cause the sum of valid N across gender or age groups to differ from the total number.

Table9 : Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the lower bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Children	Number of consumers *	Exposure in ng/kg BW per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	316	3.94	3.07	10.74	0.52	0.41	1.43
Male	153	3.65	2.75	8.39	0.49	0.37	1.12
Female	164	4.21	3.13	14.75	0.56	0.42	1.96
1-< 2 years	38	4.68	3.74	14.44	0.62	0.50	1.92
2-< 3 years	58	3.62	3.50	7.24	0.48	0.47	0.96
⩾ 3 years	219	3.90	2.88	10.85	0.52	0.38	1.44

*Due to sample weightings, rounding is prevalent and may cause the sum of valid N across gender or age groups to differ from the total.

Table10: Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of organic chicken eggs using the lower bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Children	Number of consumers *	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	316	0.81	0.63	2.20	0.73	0.57	2.00
Male	153	0.75	0.56	1.72	0.68	0.51	1.56
Female	164	0.86	0.64	3.02	0.78	0.58	2.74
1-< 2 years	38	0.96	0.77	2.96	0.87	0.70	2.69
2-< 3 years	58	0.74	0.72	1.48	0.67	0.65	1.35
⩾ 3 years	219	0.80	0.59	2.22	0.73	0.54	2.02

*Due to sample weightings, rounding is prevalent and may cause the sum of valid N across gender or age groups to differ from the total number.

The consumption studies used in the preparatory work date from 2005 (NVS-II) and 2016 (KiESEL). While the data from the KiESEL study is relatively recent, this is not the case for NVS-II. It is possible that egg consumption has changed since the study was conducted. In the case of children, a comparison with the previous VELS study shows that egg consumption (excluding industrially processed eggs) has increased by 22–45 %, depending on the age group (Kolbaum et al. 2023) . If a similar trend exists among adults, the data presented here would underestimate the exposure.

When analysing consumption data, the KiESEL study also took into account the consumption of dishes containing egg. These include dishes that consist mainly of egg, such as omelettes, but which also contain other food components that could not be excluded in all cases. This leads to a slight overestimation of exposure. At the same time, there are also dishes containing egg that were not taken into account because they did not consist mainly of egg, but it was not possible to break them down into individual ingredients in the time available. However, it is assumed that the effect on the amount consumed is minor.

The assumption in the three scenarios that consumption consists of 100 % eggs from one of the three farming systems is not always reflected in reality. For example, if a person does not consume 100 % free-range eggs, but rather mostly free-range eggs, the consumption of barn eggs would lead to lower exposure. The opposite effect would occur in a person who eats mostly barn eggs. Similarly, the type of farming used for industrially processed eggs often cannot be taken into account in consumers' purchasing decisions. In this respect, the scenarios represent the range of possible exposures, and the intake levels lie between these estimates according to the individually selected ratio and the proportion of industrially processed free-range/organic/barn eggs.

With the analytical detection methods for PFAS used for the present data set, the concentrations for the sum of PFOS, PFOA, PFNA and PFHxS in chicken eggs are below the LOQ for a high percentage of samples (76 %). This leads to considerable uncertainty in the exposure assessments. The limit of quantification (LOQ) should continue to be lowered in order to clarify whether the high proportion of unquantified values is due to the absence of PFAS in the food examined (assumption made in the LB approach) or whether, with lower limit of detection (LOD), the proportion of determinable values and thus exposure increases considerably.

In the case of the occurrence data, measurements were excluded where the sampling reasons suggest non-representative sampling; this is the case for the data evaluation from 2018 to 2022. However, it cannot be ruled out that samples with risk-oriented sampling are still present in this data set, which would tend to lead to an overestimation of exposure. The data from 2024 comes from randomly selected samples from food monitoring.

3.1.3 Risk characterisation

To characterise the potential health risks associated with the exposure to PFAS from chicken eggs, the model-based exposure assessments listed in Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.** were compared with the EFSA-derived TWI of 4.4 nanograms (ng) per kilogram (kg) of body weight per week for the sum of four PFAS (PFOS, PFOA, PFNA and PFHxS) (EFSA 2020) . The results are summarised inTable11 (LB) and Chapter 5.4 ,Table23 (UB).

For **adults**, based on the occurrence data from the 2024 monitoring, the estimated long-term exposure to the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) through the consumption of chicken eggs from various farming systems falls within the range of 0.002–0.17 ng/kg bw per week (50th percentile, LB). This means that the estimated exposure reaches 0.05–4 % (50th percentile, LB) of the TWI of 4.4 ng/kg bw per week (Table11). The estimated high exposure reaches 0.1–11 % (95th percentile, LB) of the TWI. When comparing the three scenarios for the consumption of eggs long-term PFAS exposure in adults is highest in case of assumption of the consumption of free-range and organic eggs (8–11 % of the TWI in the 95th percentile).

In **children,** long-term exposure to PFAS through the consumption of chicken eggs is approximately three to five times higher compared to adults in all scenarios. The long-term exposure of children in Germany (all) to the sum of the four PFAS through the consumption of chicken eggs lies in the range of 0.01 to 0.57 ng/kg bw per week (50th percentile) and 0.02 to 2.00 ng/kg bw per week. (95th percentile). This corresponds to 0.2–13 % (50th percentile) and 0.5–45 % (95th percentile) of the TWI of 4.4 ng/kg bw per week (Table11). As with adults, when comparing the three scenarios, the long-term PFAS exposure of children is highest when consuming free-range and organic eggs is assumed (33–45 % of the TWI in the 95th percentile).

A comparison of available data shows that the average PFAS concentrations in eggs from all production types have declined over the years. For example, the average PFAS concentrations in chicken eggs in the 2007–2020 data set are 0.36 µg/kg (95th percentile: 1.6 µg/kg), in the years 2018–2022 at 0.29 µg/kg (95th percentile: 1.00 µg/kg) and in the 2024 monitoring at 0.06 µg/kg (95th percentile: 0.42 µg/kg). This corresponds to a four- to six-fold decrease in PFAS concentrations in chicken eggs. The decline in PFAS concentrations is most pronounced in recent years (2018–2022 compared to 2024). As PFAS concentrations in chicken eggs, especially in eggs from barn and free-range farming, are lower than in 2018–2022, exposure for adults and children is currently lower: while the exposure estimated for children based on the 2018–2022 occurrence data exceeds the TWI (scenario

2: free-range; 95th percentile, LB), exposure based on monitoring data from 2024 (LB) reaches a maximum of 45 % of the TWI (scenario 3, 95th percentile).

Table11 : Estimated exposure via the consumption of chicken eggs from different farming systems compared to the TWI of 4.4 ng/kg bw per week (EFSA 2020) for the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) for different age groups of the German population using the lower bound approach. For comparison, the respective median (P50) and high (95th percentile, P95) exposure based on the occurrence data from two survey periods (2018–2022, 2024) is shown.

Group	% TWI based on occurrence data from 2018–2022						% TWI based on occurrence data from 2024					
	Barn-raised		Free-range farming		Organic production		Barn-raised		Free-range farming		Organic production	
	P50	P95	P50	P95	P50	P95	P50	P95	P50	P95	P50	P95
Adults[a] 14–80 years	2	6	20	62	4	13	0.05	0.1	3	8	4	11
Children[b] 0.5 - ≤ 5 years	7	25	70	**244**	14	50	0.2	0.5	9	33	13	45

[a] Underlying consumption study: NVS-II

[b] Underlying consumption study: KiESEL

Conclusion

The exposure assessment shows that the consumption of chicken eggs – especially from free-range or organic production – can contribute considerably to overall exposure to PFAS. However, a comparison of available data shows that the average PFAS concentrations in eggs from all production types have declined over the years. It should be noted that the exposure assessment for PFAS is subject to uncertainty.

Due to the ubiquitous prevalence of PFAS in the environment, in numerous consumer products and other food, overall exposure is composed of contributions from many different sources of exposure. For adults in Germany, long-term total exposure to the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) through the consumption of food, excluding drinking water, at average concentrations is approximately two times (mean) to five times (95th percentile) the TWI (BfR 2021). The estimate of external exposure in children (aged 1 to 9) is two to three times higher than the level of exposure in adults, partly due to higher consumption amounts relative to body weight. According to EFSA (2020), exposure above the TWI in parts of the population gives rise to health concerns.

Overall, the estimate of total exposure to PFAS is associated with considerable uncertainty. In particular, statements on the contribution of individual food groups to total exposure through food are subject to considerable uncertainty.

3.2 Risk management options, recommended measures

Optimisation and use of existing sensitive analytical methods

In the present data set, the concentrations of PFOS, PFOA, PFNA and PFHxS in chicken eggs are below the limits of quantification (LOQ) of the analytical methods used here for PFAS in a high percentage of samples (56–91 %). This leads to considerable uncertainty in the exposure assessments. The optimisation or use of existing sensitive analytical methods could lead to a further reduction in the limits of quantification (LOQ) and thus contribute to reducing uncertainties.

Considerations for reducing the entry of PFAS into feed, soil and water

Consumers have limited influence over their exposure to PFAS, as these chemicals are ubiquitous environmental contaminants. The occurrence of PFAS in food can be influenced primarily by avoiding and sealing off sources of environmental contamination.

Various pathways are being discussed regarding the occurrence of PFAS in chicken eggs, e.g. intake via feed, soil and water. Identifying the respective sources of entry can enable minimisation such inputs and contribute to reducing the PFAS levels in chicken eggs. For this reason, the following analysis uses mathematical models based on the PFAS concentrations in chicken eggs (monitoring data 2024) to estimate the exposure of laying hens. Taking into account usual intake amounts, conclusions are drawn about the PFAS concentrations in the potential entry matrices feed, soil and water.

PFAS exposure in laying hens

PFAS are ubiquitous in the environment and can be ingested by chickens via feed and drinking water as well as via the soil, including soil organisms (e.g. worms, insects) (Kowalczyk et al. 2020; LUbw 2021; Wilson et al. 2021).

The intake of soil and soil organisms can vary among chickens depending on the farming conditions (Jurjanz et al. 2015). In organic production and free-range farming, chickens can engage in their natural exploratory, pecking and scratching behaviour. In doing so, they also ingest plants, soil and soil organisms (worms/insects) to supplement their nutrient supply. Chickens from organic production and free-range farming with outdoor access therefore consume more soil than animals kept in barns with litter, i.e. from barn-raising systems. The amount of soil consumed by chickens depends on the vegetative soil cover and the season (Jurjanz et al. 2015) . Long-chain PFAS bind particularly well to soil particles and are relatively immobile (Lv et al. 2023) . The compounds most commonly detected in soil include the long-chain compounds PFOA and PFOS (LANUV 2024; Lv et al. 2023).

Plants absorb PFAS from the soil via their roots (Stahl et al. 2009). Data collected as part of a national feed monitoring programme show very low background levels of PFOA, PFNA, PFOS and PFHxS in plant-based feed. Despite a high proportion of left-censored data (the proportion of data below the limits of quantification (LOQ) was 81 %), no concentrations of PFOA, PFDA, PFHxS or PFOS exceeding the limits of quantification (0.01–0.3 µg/kg) were detected in rapeseed meal and whole-grain wheat-feedstuffs relevant to poultry. Due to the accumulation behaviour in protein-rich matrices, higher concentrations of PFOS, PFOA, PFHxS and PFNA can be detected in feedstuffs of animal origin, such as fish meal (Li et al. 2019; Suominen et al. 2011). Suominen et al. (2011) published PFOS concentrations in the range of 0.9 to 20 mg/kg for fish meal traded in Europe with 88 % dry matter. PFAS monitoring in Danish eggs showed that fishmeal in rations for laying hens can be a major source of PFAS transfer to chicken eggs (Granby et al. 2024). Replacing contaminated fishmeal with other protein feed in the rations led to rapid washout. Based on average PFOS concentrations of 0.9 µg/kg and a value of 1.1 µg/kg for the sum of the four EFSA PFAS in chicken eggs, PFAS concentrations below the limit of quantification (LOQ) of 0.05 µg/kg were achieved within a few weeks. Chickens in organic production and free-range farming meet their protein requirements by the intake of soil organisms such as worms and insects in addition to their feed (Jurjanz et al. 2015). Studies on earthworms, woodlice and beetles indicate a strong accumulation capacity for PFAS from the soil, especially for PFOS (Burkhard and Votava 2022; Fremlin et al. 2023), and it can be assumed that worms and insects may be a substantial source of PFAS for chickens in organic production and free-range farming due to their PFAS accumulation potential.

Another possible source of exposure to PFAS for laying hens is their drinking water, which can come from various sources (e.g. tap water, well water, surface water) with different sources of PFAS input (e.g. fire-fighting foams, landfill residues, industrial emissions). Studies on transfer in laying hens show a strong linear correlation between the concentrations of PFOA, PFHxS and PFOS in drinking water and in chicken eggs. Taking into account the possible daily fluctuations in drinking water intake, the PFOS concentrations in eggs correlate particularly closely with daily PFOS intake (Wilson et al. 2021) .

Transfer of PFAS into chicken eggs

It is assumed that the absorption of PFAS from the digestive tract into the animal's body is almost 100 % and occurs independently of the matrix (feed, water, soil). PFAS ingested orally are then rapidly excreted by laying hens in faeces, urine and eggs. The proportion excreted in the egg varies depending on the PFAS compound (Drew et al. 2021; Kowalczyk et al. 2020). 99% of the PFAS excreted in the egg is found in the egg yolk (Göckener et al. 2020). The BfR conducted a feeding study with laying hens (Lohmann brown) on the transfer of PFAS from contaminated feed and determined transfer rates for PFOA, PFOS and PFHxS in eggs after a 25-day exposure phase (Kowalczyk et al. 2020). PFOS showed an almost complete transfer rate to chicken eggs (99 %), while the transfer rate of PFOA was approximately 49 %. From the subsequent 42-day elimination phase with PFAS-free feed, elimination half-lives in eggs of 4.5 days for PFOA, 4.3 days for PFOS and 7.6 days for PFHxS were derived. The values for PFNA are extrapolated from those for PFOS using read-across (100 % transfer rate). Comparable mean transfer rates (50%, 110% and 70%) and half-lives (5.4, 3.5 and 7 days) for PFOA, PFOS and PFHxS were described in a study on laying hens after exposure via PFAS-contaminated drinking water (Wilson et al. 2021).

Taking transfer into account, it is possible to estimate the level of daily oral exposure of laying hens via feed, drinking water or the soil, including soil organisms, required to result in PFAS concentrations in chicken eggs determined in the 2024 food monitoring programme (Table12). Due to the substantial influence of the limits of quantification on the calculation of total PFAS exposure and the PFAS concentrations in the exposure sources relevant to laying hens, the LB approach is considered to be the more realistic scenario. For laying hens, values for the exposure to the sum of PFOA, PFNA and PFHxS were determined in the range of nanograms per day. These levels are negligible compared to the total exposure to PFOS, consequently, these substances are not further discussed below. An analysis of PFOS values by farming method reveals that total exposure for laying hens in free-range and organic systems is 100 times higher than for those in barn systems (Table12). Under the assumption that exposure to PFOS results exclusively from intake through feed, soil or water, PFOS concentrations were estimated for each individual matrix:

Table12: Average total PFOS exposure of laying hens calculated on the basis of the average PFOS concentrations ("lower bound" approach) in chicken eggs in the 2024 monitoring. Under the assumption that 100 % of this PFOS exposure originated from feed, soil or water, PFOS concentrations were estimated for each individual matrix.

Type of farming	Total exposure (µg/animal per day)	Feed [(1)] (µg/kg DA)	Soil [2] (µg/kg OS)	Water [3] (µg/litre)
Barn-raised	0.00004	0.0004	N/A	0.0002
Free-range	0.0029	0.026	0.10 - 0.58	0.013
Organic production	0.0042	0.036	0.14 - 0.82	0.018

Parameters: [1] Feed intake 115 g/day; [2] Soil intake 5-30 g/day; [3] Drinking water intake 230 ml/day; n.a. no soil intake in this type of farming.

Taking into account normal feed intake amounts, PFOS concentrations in feed were estimated that lead to transfer into chicken eggs but would not be quantifiable with the limit of quantification (LOQ) of 0.1 µg/kg currently recommended by the European Commission for feed. A comparison with the BfR guidance values for PFAS in feed (BfR 2023) shows that when laying hens are fed feed with the PFOS concentrations determined in Table 12, the maximum concentrations specified in Regulation (EU) 2023/915 for eggs are not exceeded over the entire laying period.

Assuming that the calculated PFOS exposure of the hen results exclusively from soil ingestion, estimates were made regarding the potential PFOS concentrations in soil that would lead to the concentrations found in the monitoring of free-range or organic chicken eggs of 0.06 and 0.09 µg/kg fresh weight, respectively. It was supposed that free-range and organic laying hens ingest between 5 g and 30 g of soil per animal per day. This results in soil PFOS levels of between 0.10 and 0.58 and 0.14 and 0.82 µg/kg, respectively. The soil levels calculated for a daily soil intake of 5 g correspond to 64 % and 90 % of the background value for PFOS of 0.91 µg/kg (90th percentile, topsoil 0–10 cm) derived for grassland soil in North Rhine-Westphalia (LANUV 2024).

Based on the 2024 monitoring data, the PFAS concentrations in eggs from barn-raised hens are far lower than in eggs from free-range and organic production. Since a major difference between the types of farming lies in the opportunity for outdoor access, concentration differences may be attributable to the additional entry route of PFAS via the soil.

Based on the available data, the BfR concludes that, in addition to water and feed, soil should also be considered as a source of exposure for laying hens in organic and free-range production.

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5 Appendix

5.1 Limits of quantification (LOQ)

Table13: Temporal trend in the mean limits of quantification reported by the German federal states.

Limits of quantification (LOQ) (mean values)	PFOS in µg/kg	PFOA in µg/kg	PFNA in µg/kg	PFHxS in µg/kg
2021	0.52	0.51	1.00	1.00
2018–2022	0.41	0.42	0.42	0.40
2024	0.38	0.37	0.37	0.38

5.2 Exposure to PFAS through the consumption of chicken eggs, differentiated by farming methods and using the upper bound approach

Table14: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the upper bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	15,250	1.25	1.01	3.14	0.37	0.30	0.94
Male	7,558	1.30	1.03	3.38	0.39	0.31	1.01
Female	7,692	1.21	0.99	2.97	0.36	0.30	0.88

Table15: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the upper bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	P50	P95	MV	P50	P95
All	15,250	1.71	1.38	4.30	0.53	0.42	1.32
Male	7,558	1.78	1.40	4.63	0.55	0.43	1.42
Female	7,692	1.65	1.36	4.06	0.51	0.42	1.25

Table16: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of organic chicken eggs using the upper bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	P50	P95	MV	P50	P95
All	15,250	0.79	0.64	1.98	0.35	0.28	0.88
Male	7,558	0.82	0.65	2.14	0.36	0.29	0.95
Female	7,692	0.76	0.63	1.87	0.34	0.28	0.83

Table17: Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the upper bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Children	Number of consumers*	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	316	4.57	3.56	12.46	1.35	1.05	3.68
Male	153	4.24	3.19	9.74	1.25	0.94	2.87
Female	164	4.88	3.63	17.12	1.44	1.07	5.05
1-< 2 years	38	5.43	4.34	16.76	1.60	1.28	4.95
2-< 3 years	58	4.20	4.06	8.41	1.24	1.20	2.48
⩾ 3 years	219	4.53	3.34	12.59	1.34	0.99	3.72

*Due to sample weightings, rounding can result in the fact that the integer sums of the numbers may not be identical.

Table18: Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of free-range chicken eggs using the upper bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Children	Number of consumers*	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	316	6.22	4.84	16.95	1.93	1.50	5.27
Male	153	5.77	4.34	13.24	1.79	1.35	4.11
Female	164	6.64	4.94	23.29	2.06	1.54	7.23
1-< 2 years	38	7.38	5.91	22.80	2.29	1.84	7.08
2-< 3 years	58	5.72	5.52	11.43	1.78	1.72	3.55
⩾ 3 years	219	6.16	4.55	17.13	1.91	1.41	5.32

*Due to sample weightings, rounding can result in the fact that the integer sums of the numbers may not be identical.

Table19: Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of organic chicken eggs using the upper bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from two survey periods (2018–2022, 2024).

Children	Number of consumers*	Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**
All	316	2.89	2.25	7.88	1.28	1.00	3.49
Male	153	2.68	2.02	6.16	1.19	0.89	2.73
Female	164	3.09	2.30	10.83	1.37	1.02	4.80
1-< 2 years	38	3.43	2.75	10.60	1.52	1.22	4.70
2-< 3 years	58	2.66	2.57	5.32	1.18	1.14	2.36
⩾ 3 years	219	2.86	2.11	7.96	1.27	0.94	3.53

*Due to sample weightings, rounding can result in the fact that the integer sums of the numbers may not be identical.

5.3 Exposure to PFAS through the consumption of chicken eggs (all production types)

Table 20: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of chicken eggs of all production types using the lower bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from three survey periods (2021, 2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2007–2020 (BfR 2021[a])			Exposure In ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**	**MV**	**P50**	**P95**
All	15,250	0.79	0.64	1.98	0.64	0.51	1.60	0.13	0.11	0.33
Male	7,558	0.82	0.65	2.14	0.66	0.52	1.72	0.14	0.11	0.36
Female	7,692	0.76	0.63	1.87	0.61	0.51	1.51	0.13	0.10	0.31

[a] In the 2021 opinion, the 24-hour recalls of the NVS-II were used for consumption, partly to facilitate a better comparison to the EFSA opinion. However, as the DISHES data better reflect long-term exposure, provided that the food is consumed regularly and by a large proportion of the population, the DISHES data were used for eggs in this opinion. The estimates therefore differ from the intake estimates for eggs presented in the 2021 opinion.

Table20: Estimated long-term exposure of adults to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of chicken eggs of all production types using the upper bound approach (consumption data based on NVS-II, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from three survey periods (2021, 2018–2022, 2024).

Adults	Number of consumers	Exposure in ng/kg bw per week based on occurrence data from 2007–2020 (BfR 2021[a])			Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**	**MV**	**P50**	**P95**
All	15,250	1.89	1.52	4.74	1.40	1.13	3.53	0.46	0.37	1.16
Male	7,558	1.96	1.55	5.10	1.46	1.15	3.80	0.48	0.38	1.25
Female	7,692	1.82	1.50	4.47	1.35	1.11	3.33	0.44	0.37	1.09

[a] In the 2021 opinion, the 24-hour recalls of the NVS-II were used for consumption, partly to facilitate a better comparison to the EFSA opinion. However, as the DISHES data better reflect long-term exposure, provided that the food is consumed regularly and by a large proportion of the population, the DISHES data were used for eggs in this opinion. This is why the estimates differ from the intake estimates for eggs presented in the 2021 opinion.

Table21: Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of chicken eggs of all production types using the lower bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from three survey periods (2021, 2018–2022, 2024).

Children	Number of consumers*	Exposure in ng/kg bw per week based on occurrence data from 2007–2020 (BfR 2021[b])			Exposure in ng/kg bw per week based on occurrence data from 2018–2022			Exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	**P50**	**P95**	**MV**	**P50**	**P95**	**MV**	**P50**	**P95**
All	316	2.87	2.24	7.83	2.29	1.79	6.25	0.48	0.38	1.31
Male	153	1.99	2.99	2.99	2.13	1.60	4.89	0.45	0.34	1.03
Female	164	3.41	2.73	10.53	2.45	1.82	8.59	0.51	0.38	1.80
1-< 2 years	38	2.64	2.55	5.28	2.72	2.18	8.41	0.57	0.46	1.77
2-< 3 years	58	2.85	2.10	7.91	2.11	2.04	4.22	0.44	0.43	0.89
⩾ 3 years	219	2.66	2.01	6.12	2.27	1.68	6.32	0.48	0.35	1.33

*Due to sample weightings, rounding can result in the fact that the integer sums of the numbers may not be identical.

[b] In the 2021 opinion on total exposure to PFAS, exposure in children was calculated using the VELS study. As we now have access to more recent data, we have recalculated exposure in the KiESEL study using the 2021 concentrations.

Table22: Estimated long-term exposure of children to the sum of PFOS, PFOA, PFNA and PFHxS through the consumption of chicken eggs of all production types using the upper bound approach (consumption data based on KiESEL, consumers only). For comparison, the respective mean (MV), median (P50) and high (95th percentile, P95) exposure is shown based on the occurrence data from three survey periods (2021, 2018–2022, 2024).

Children	Number of consumers*	Exposure in ng/kg bw per week] based on occurrence data from 2007–2020 (BfR 2021[b])			Exposure in ng/kg bw per week based on occurrence data from 2018–2022			exposure in ng/kg bw per week based on occurrence data from 2024		
		MV	P50	P95	MV	P50	P95	MV	P50	P95
All	316	6.86	5.34	18.71	5.11	3.98	13.93	1.67	1.30	4.55
Male	153	6.36	4.79	14.62	4.74	3.57	10.89	1.55	1.17	3.55
Female	164	7.33	5.45	25.69	5.46	4.06	19.14	1.78	1.33	6.25
1-< 2 years	38	8.14	6.52	25.16	6.07	4.86	18.74	1.98	1.58	6.11
2-< 3 years	58	6.31	6.10	12.62	4.70	4.54	9.40	1.53	1.48	3.07
⩾ 3 years	219	6.80	5.02	18.90	5.06	3.74	14.08	1.65	1.22	4.59

*Due to sample weightings, rounding can result in the fact that the integer sums of the numbers may not be identical.

[b]In the 2021 opinion on total exposure to PFAS, exposure in children was calculated using the VELS study. As more recent data is now available, exposure in the KiESEL study was recalculated using the 2021 concentrations.

5.4 Estimated exposure to PFAS through the consumption of chicken eggs compared to the TWI using the upper bound approach

Table23 : Estimated exposure via the consumption of chicken eggs from different farming systems compared to the TWI of 4.4 ng/kg bw/week (EFSA 2020) for the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) for different age groups of the German population using the upper bound approach.

Group	% TWI based on occurrence data from 2018–2022						% TWI based on occurrence data from 2024					
	Barn-raised		**Free-range farming**		**Organic production**		**Barn-raised**		**Free-range farming**		**Organic production**	
	P50	**P95**	**P50**	**P95**	**P50**	**P95**	**P50**	**P95**	**P50**	**P95**	**P50**	**P95**
Adults[1] 14–80 years	23	71	31	98	15	45	7	21	10	30	6	20
Children[2] 0.5 - ≤ 5 years	81	283	110	385	51	179	24	84	34	120	23	79

[1] based on the NVS II Study

[2] based on the KiESEL Study

Table24: Estimated exposure via the consumption of chicken eggs from all production types compared to the TWI of 4.4 ng/kg bw/week (EFSA 2020) for the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) for different age groups of the German population and using the lower bound approach.

Group	% TWI based on occurrence data from 2007–2020 (BfR 2021a)		% TWI based on occurrence data from 2018–2022		% TWI based on occurrence data from 2024	
	P50	**P95**	**P50**	**P95**	**P50**	**P95**
Adults[1] 14 - 80 years	15	45	12	36	3	8
Children[2] 0.5 - ≤ 5 years	51	178	41	142	9	30

[a]In the 2021 opinion on total exposure to PFAS exposure in children was calculated using the VELS study. As more recent data is now available, exposure in the KiESEL study was recalculated using the 2021 concentrations.

1 based on the NVS II Study

2 based on the KiESEL Study

Table25: Estimated exposure via the consumption of chicken eggs from all production types compared to the TWI of 4.4 ng/kg bw per week (EFSA 2020) for the sum of the four PFAS (PFOS, PFOA, PFNA and PFHxS) for different age groups of the German population and using the upper bound approach.

Group	% TWI based on occurrence data from 2007–2020 (BfR 2021[a])		% TWI based on occurrence data from 2018–2022		% TWI based on occurrence data from 2024	
	P50	**P95**	**P50**	**P95**	**P50**	**P95**
Adults[1] 14–80 years	35	108	26	80	8	26
Children [2] 0.5 - ≤ 5 years	121	425	90	317	30	103

[a] In the 2021 opinion on overall exposure to PFAS, exposure in children was calculated using the VELS study. As more recent data is now available, exposure in the KiESEL study was recalculated using the 2021 concentrations.

[1] based on the NVS II Study

[2] based on the KiESEL Study

About the BfR

The German Federal Institute for Risk Assessment (BfR) is a scientifically independent institution within the portfolio of the German Federal Ministry of Agriculture, Food and Regional Identity (BMLEH). It protects people's health preventively in the fields of public health and veterinary public health. The BfR provides advice to the Federal Government as well as the Federal States (‘Laender’) on questions related to food, feed, chemical and product safety. The BfR conducts its own research on topics closely related to its assessment tasks.

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Publisher:
German Federal Institute for Risk Assessment
Max-Dohrn-Straße 8-10
10589 Berlin, Germany
T +49 30 18412-0
F +49 30 18412-99099
bfr@bfr.bund.de
bfr.bund.de/en

Institution under public law
Represented by the President Professor Dr Dr Dr h. c. Andreas Hensel
Supervisory Authority: Federal Ministry of Agriculture, Food and Regional Identity
VAT ID No. DE 165 893 448
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