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PFAS eilífðarefni í eggjum

Per and Polyfluoroalkyl Substances in Icelandic eggs

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Executive Summary:	Per- and poly-fluoroalkyl substances (PFAS) are a class of synthetic industrial compounds used to produce water and oil-repellent coatings for products such as clothing, non-stick cookware, and fast-food packaging. The major route of exposure to these chemicals is through ingestion of contaminated food and water, however status of PFAS pollution in Iceland remains largely unknown. This project will provide essential information on the PFAS content of domestically produced eggs and feed to ensure the egg products are safe for consumption. PFAS concentrations were found to be well below EU maximum levels for all commercially produced eggs analysed, including those from the years 2016-2022. However, home-produced eggs collected near Keflavík international airport (Garður) contained high levels of PFAS which exceeded EU maximum levels for PFOS during the Summer. There were no direct links between the levels of PFAS found in feed and eggs, and the degree of contamination is more likely linked to the location where hens are kept and the length of time spent outdoors. From these results it was concluded that the inclusion of fishmeal in laying hen feed did not increase PFAS levels in eggs produced in Iceland. This project has shown that free-range Icelandic eggs and the majority of home-produced eggs (depending on location) are safe for consumers. However, commercially produced eggs are significantly safer for children and those consuming high numbers of eggs per week. Eggs produced in Iceland were rich in essential trace elements (Fe, Zn and Se), minerals (Na, Mg, P, K and Ca), unsaturated fatty acids and Omega-3, and are an important protein source for nearly all demographics of consumers. Commercially produced eggs were also low in heavy metals, however, relatively high levels of Pb were detected in egg samples collected near Keflavík and concentrations were seven times higher than all other samples. These results could prompt further expansion of commercial egg production in Iceland, which would in turn would reduce the reliance on imported sources for during shortages or for industries such as hospitality. This important work may also lead to further investigation of PFAS and Pb contamination arising from Keflavík airport and how this may be impacting the health of those living in this area.
English keywords:	*Egg, polyfluoroalkyl substances, PFAS, heavy metals, fatty acids, minerals*

Abbreviations

4:2 FTS	1H,1H,2H,2H-Perfluorohexanesulfonate
6:2 FTS	1H,1H,2H,2H-Perfluorooctanesulfonate
8:2 FTS	1H,1H,2H,2H-Perfluorodecanesulfonate
3:3 FTCA	2H,2H,3H,3H-Perfluorohexanoic acid
5:3 FTCA	2H,2H,3H,3H-Perfluorooctanoic acid
7:3 FTCA	2H,2H,3H,3H-Perfluorodecanoic acid
9ClPF3ONS (F-53B major)	9-Chlorohexadecafluoro-3-oxanone-1-sulfonic acid
11ClPFOUdS (F-53B minor)	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
ADONA	Ammonium 4,8-dioxa-3H-perfluorononanoate
CRM	Certified reference material
dSPE	dispersive Solid Phase Extraction
EFSA	European Food Safety Authority
EU	European Union
FAME	Fatty Acid Methyl Ester
FOSA (PFOSA)	Perfluorooctane sulfonamide
GC-FID	Gas Chromatography-Flame Ionisation Detector
GenX (HPDO-DA)	Hexafluoropropylene oxide-dimer acid
H-ESI	Heated-Electrospray Ionisation
HPLC	High Performance Liquid Chromatography
ICP-MS	Inductively Coupled Plasma-Mass Spectrometer
iAs	Inorganic arsenic
MS	Mass Spectrometer
MUFA	Mono-unsaturated fatty acid
NFDHA	Nonafluoro-3,6-dioxaheptanoic acid
N-MeFOSA	N-Methylperfluorooctanesulfonamide
N-MeFOSAA	N-Methylperfluorooctanesulfonamido acetic acid
N-MeFOSE	N-Methylperfluorooctancesulfonamidoethanol
N-EtFOSA	N-Ethylperfluorooctanesulfonamide
N-EtFOSAA	N-Ethylperfluorooctanesulfonamido acetic acid
N-EtFOSE	N-Ethylperfluorooctancesulfonamidoethanol
PFAS	Per- and polyfluoroalkyl Substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutanesulfonic acid
PFDA	Perfluorodecanoic acid
PFDS	Perfluorodecanesulfonic acid
PFDoDA	Perfluorododecanoic acid
PFDoDS	Perfluorododecanesulfonic acid
PFEESA	Perfluoro(2-ethoxyethane) sulfonic acid
PFHpA	Perfluoroheptanoic acid
PFHpS	Perfluoroheptanesulphonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexanesulphonic acid

PFMBA	Perfluoro-3-methoxybutanoic acid
PFMPA	Perfluoro-3-methoxypropanoic acid
PFNA	Perfluorononanoic acid
PFNS	Perfluorononanesulfonic acid
PFOA	Perflurooctanoic acid
PFOS	Perfluorooctanesulphonic acid
PFPeA	Perfluoropentanoic acid
PFPeS	Perfluoropentanesulfonic acid
PFTriDA	Perfluorotridecanoic acid
PFTeDA	Perfluorotetradecanoic acid
PFUnDA	Perfluoroundecanoic acid
PUFA	Poly-unsaturated fatty acid
SFA	Saturated fatty acid
SRM	Selected Reaction Monitoring

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Introduction

Per- and polyfluoroalkyl substances (PFAS) are a class of synthetic industrial compounds used to produce water and oil-repellent coatings for products such as clothing, non-stick cookware, and fast-food packaging. These "forever chemicals" are extremely persistent and are now widespread throughout the environment, with alarming levels of PFAS being reported as far North as Svalbard and the Arctic circle(1). Nearly every human worldwide is expected to have been exposed to PFAS, with one European study detecting PFAS in 100% of the blood of teenagers sampled from 9 different countries(2). All PFAS compounds share the same general structure – a carbon-chain backbone of varying length saturated with fluorine atoms, Figure 1. Perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) have been extensively studied and have been shown to accumulate in bone and liver tissues after consumption. PFOA has also recently been classed as carcinogenic to humans (group 1) by the International Agency for Research on Cancer (3). Exposure has also been linked to thyroid disease, liver damage, and decreased fertility (4). Although less is known about the toxicity of other PFAS compounds, they are suspected to be endocrine disrupting, and accumulation has been demonstrated in brain, kidney, and lung tissues (5). Novel or emerging compounds such as ADONA and HFPO-DA (Gen X), which were synthesised as replacements for PFOA, have shown considerable hepatotoxicity in animal models (6). Chlorinated F-53B compounds have additionally been found to be most accumulative in human to date, with a half-life of approximately 15.3 years (7). The wide chemical diversity of PFAS means that there is potential for almost every organ to be affected, and there are concerns over the unknown toxicological effects from being exposed to a “cocktail” of different PFAS.

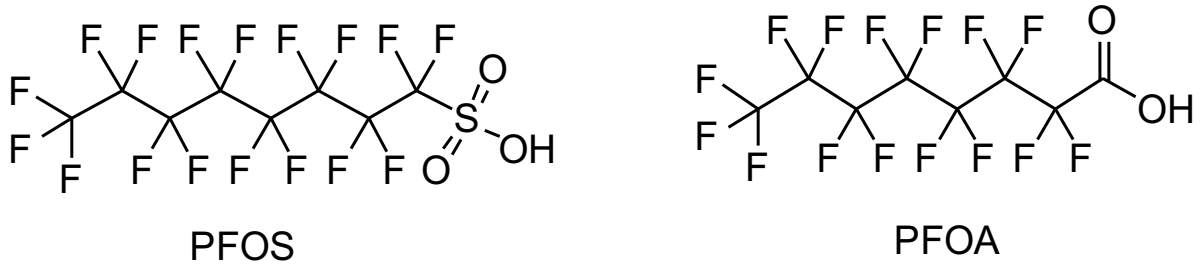

Figure 1. The structure of PFOS and PFOA.

The major exposure route of PFAS is through ingestion of contaminated drinking water and food products, with very minor contributions from inhalation and dermal contact. The European Food Safety Authority (EFSA) has defined a safe weekly intake of 4.4 ng kg^{-1} of body weight for the sum of four PFAS compounds (PFOA, PFOS, PFHxS and PFNA) (8). Anything above this limit is expected to cause detrimental health effects, and PFAS-related ailments are predicted to cost health services in Europe an additional €52-84 billion annually(9). Meat, fish, and egg products have been found to contribute significantly to dietary intake of PFAS and were also linked to high concentrations of PFAS in blood and serum (10).

A recent study carried out by Denmark Technical University (DTU) in collaboration with the Danish Veterinary and Food Administration reported relatively high levels of PFAS in organic egg yolks compared to cage- and free-range yolks (11). From these results, it is estimated that children in Denmark who consume more than 5 organic eggs a week are exposed to over double the tolerable weekly consumption, not accounting for other sources which may contribute to the total intake. The high PFAS content has been linked to the use of fish meal as a feed supplement. Thus, is it possible that eggs may be contributing significantly to the PFAS exposure of Icelandic individuals, particularly those that rely on eggs as an alternative protein source.

On the 1st of January 2023, the EU introduced maximum levels in whole eggs for the sum of the four major PFAS compounds and is expected to later introduce a similar measure for feed. These regulations will be recommended but not enforced in Iceland, so it is crucial that the PFAS content of both feed and eggs are investigated. A proposal for the complete restriction of PFAS production was also published in February 2023 and is expected to come into force in the coming years, however, the persistence of these compounds means they will be an imminent chemical pollutant for decades to come. So far, over 9000 different PFAS have been identified and this number is only expected to increase as industry develops new analogues to comply with updated regulations. Currently there is no effective way to remove PFAS from foods, and so the best course of action for consumers is to minimise exposure to these harmful chemicals. This project will provide essential information on the PFAS content of domestically produced eggs and feed to ensure the egg and egg-based products being sold to consumers are safe for consumption. The results of this project will also provide an indication of the levels of contamination in the environment and may inspire the analysis of PFAS levels in more food products in an effort to increase the safety of food produced and consumed in Iceland.

Method

Chemicals and standards

For trace element analysis

Ultrapure water was obtained from a Millipore ultrapure water dispenser. Single element standard solutions from LabKings (1000 µg mL^{-1} in 2 % nitric acid (HNO_3), The Netherlands) and Peak Performance (1000 µg mL^{-1} in 2 % HNO_3; CPI International, USA) were used to prepare standards for external calibration. Hydrogen peroxide (H_2O_2) (≥ 30 % for trace analysis) and HNO_3 (ROPITURAN, Supra 69%) were supplied by SupelCo (France) and Carl Roth (Germany) respectively. Ammonium carbonate (EMSURE ACS Reagent) came from SupelCo (Germany) and methanol (CHROMASOLV, for HPLC ≥ 99.9 %) from Honeywell (USA).

For fat determination and fatty acid composition analysis

Chloroform and isooctane (CHROMASOLV for HPLC ≥ 99.9 %) were obtained from Honeywell (Germany) and methanol (ROTISOLV, ≥ 99.98 %) was supplied by Carl Roth (Germany). Sodium sulphate (Na_2SO_4) anhydrous was purchased from Fluka Analytical and sodium chloride (NaCl) (ACS reagent, ≥ 99.0 %) was obtained from Sigma Aldrich (USA). Boron trichloride (BCl_3; 12 % in methanol for GC derivatisation) and potassium chloride (KCl) were both purchased from Sigma Aldrich (Germany).

For PFAS analysis

Acetonitrile (suitable for HPLC, ≥99.9%) and LC-grade water (LiChrosolv) were obtained from Sigma-Aldrich (Germany). Ammonium acetate (ACS reagent ≥97%) was also supplied by Sigma-Aldrich (Netherlands). Chromabond C18 SPE adsorbent was obtained from Macherey-Nagel. Supelco ENVI-carb powder, sodium chloride (ACS reagent, ≥99.9%) and magnesium sulphate (anhydrous, free-flowing, Redi-Dri, ≥99.5%) were purchased from Sigma Aldrich. A native PFAS mixture used for calibration (EPA method 1633, 10 mg L^{-1}) was purchased from LGC (UK), and mass-labelled internal (MPFAC-24ES) and injection (MPFAC-HIF-IS) were obtained from Wellington Laboratories (Canada).

Samples and reference materials

Certified reference materials (CRMs) (DORM-5, fish protein and TORT-3, lobster hepatopancreas) for trace element analysis were obtained from the National Research Council Canada. A SupelCo (Germany) 37 Component FAME Mix CRM was used for identification of fatty acids (18919-1AMP), and a dried egg quality control material (FCCE7-EGG3QC) was obtained from Fapas (UK) for the determination of PFAS.

Samples were collected from major egg-producers in Iceland across the span of 1-year, Table 1. The regular and organic laying hen feeds used by producers in Flóahreppur and Vatnsleysustönd were collected during the same sampling months. Where possible, samples were also collected from 3 independent home producers in

Grafarvogur, Garður and Njarðvík. Throughout the following report, egg products are labelled with their respective locations. Feed samples are described as either “organic” with the age group 2 or 3, or as “feed” with the age group 19-50 or 50+.

Table 1. The samples of eggs and feed collected over the duration of the project 2024-2025 from commercial producers and independent farms. Egg samples were obtained from several producers and two small independent farms. All feed samples were imported.

Sampling Month	Egg producer location	Feed
January	Flóahreppur (organic)	Organic 2 (26-49 weeks)
	Flóahreppur (organic)	Organic 3 (50+ weeks)
	Vatnsleysuströnd	Feed (19-50 weeks)
	Vatnsleysuströnd	Feed (50+ weeks)
	Hrísey	
	Hranastaður*	
	Akureryi*	
	Vallá*	
	Mosfellsbær*	
February	Independent producer (Njarðvík)**	
April	Flóahreppur,	Organic 3 (50+ weeks)
	Vatnsleysuströnd	Feed (50+ weeks)
	Hrísey	
	Akureryi	
	Vallá	
August	Flóahreppur	Organic 2 (26-49 weeks)
	Vatnsleysuströnd	Feed (19-50 weeks)
	Hrísey	
	Hranastaður	
	Akureryi	
	Vallá	
	Independent producer (Grafarvogur)	
	Independent producer (Garður)	
November	Flóahreppur	
	Vatnsleysuströnd	
	Hrísey	
	Hranastaður	
	Akureryi	
	Vallá	
	Denmark	

*2025. **Analysed only for PFAS content as eggs are not consumed.

Pooled samples were prepared by combining the contents of 10-15 individual eggs, and hand whisking until homogeneous. The pooled samples were freeze-dried (for water content determination) and then further homogenised to a fine powder. For analysis of feed, approximately 300 g of each material was homogenised to a fine powder (IKA tube mill, China) before use to ensure representative aliquots could be taken. Preserved (freeze-dried) whole egg samples (Akureyri, Hrísey, Vallá and Vaynsleysuströnd) from the years 2016, 2020 and 2022 were also included to observe potential temporal differences in PFAS contamination (Appendix T1).

Proximates

Water content

The water content of egg samples was determined through losses in mass after freeze-drying (Christ, Germany) to constant mass (48 hr). The water content of feed was determined through losses in mass after oven drying at 107°C for 24 hr.

Protein content

In duplicate, 200-250 mg of feed material or 100 mg of freeze-dried egg was accurately weighed into crucibles. For the yolks, whites and whole eggs, 99-125 mg of the freeze-dried samples were accurately weighed. The crucibles were then placed into a rapid N exceed Nitrogen and Protein analyser. Blanks and an in-house reference material (fishmeal) were also analysed. The protein composition was calculated by multiplying the nitrogen percentage composition by a protein factor of 6.25. This estimation method assumes that food proteins contain approximately 16% nitrogen, and that all nitrogen present is bound to protein.

Fat content

Approximately 25 g of fresh sample material was added to a 250 mL centrifuge bottle before adding 25 mL of chloroform and 50 mL of methanol. Samples were mixed for 2 min with an Ultra-Turrax T25 homogeniser, before the addition of 25 mL chloroform and further mixing Then 25 mL of 0.88 % (w/v) KCl solution was added, and the sample was mixed for 1 min. The samples were then centrifuged for 20 min at 2500 rpm, 4 °C and the bottom chloroform layer was transferred to a 50 mL Falcon tube. 3 mL of chloroform layer was pipetted in, chloroform evaporated overnight in fume hood and the remaining fat weighed.

Ash content

The ash content was determined through gravimetric analysis. In duplicate, 2 g of sample material was weighed into crucibles (platinum/gold, 20 cm^3) before being placed into an oven at 550°C for 3 hr. The crucibles were then transferred to a desiccator to cool before reweighing to calculate ash content.

Fatty acid composition

Sample preparation

Approximately 2 mL of the chloroform layer from the fat determination was pipetted into glass vials, in duplicate. The chloroform solvent was evaporated at 55°C using a flow of nitrogen, before adding 1.5 mL of 0.5 M sodium hydroxide was added to each vial. Samples were then mixed and heated at 100°C for 7 min. After cooling, 2 mL of BCl_3, 12% in methanol was added and then samples were heated for a further 30 min at 100°C. Once cool, 1 mL of a methyl tricosanoate internal standard dissolved in isooctane and 5 mL of concentrated NaCl solution were added and the mixture vortexed for 30 s. Once the layers had separated, the upper isooctane layer was pipetted into a smaller vial with Na_2SO_4 and 1 mL of isooctane was added to the original vial, mixed for 30 s and the upper layer was pipetted into the smaller vial. Finally, 1.5 mL of the isooctane layer was pipetted into liquid chromatography vials for analysis.

Analysis

Fatty acid methyl esters (FAME) were separated on a ThermoScientific Trace 1610 GC-FID equipped with a TG-WaxMS (polyethylene glycol) column (30 m x 0.25 mm, 0.25 μm), split injection and flame ionization detector. The temperature gradient was as follows: 100 °C for 0-4 min, then raised to 240 °C at 3 °C min^{-1} and held at this temperature for 15 min. The injector and detector temperature were set to 245°C and 285 °C, respectively. The carrier gas used was helium at a flow rate of 0.8 mL min^{-1}, purge flow of 5.0 L min^{-1} and split ratio of 20:1. Peak identification was performed through comparison with a known fatty acid methyl ester standard mixture.

Trace elements, toxic elements and minerals

Sample preparation

In triplicate, approximately 200 mg of freeze-dried sample material was weighed into 12 mL quartz digestion tubes before the addition of 1 mL of nitric acid (HYPERPURE, >69%) and 1 mL of hydrogen peroxide (TraceSELECT, >30%). Sample mixtures were added to the reaction chamber of an Ultrawave Microwave Digestion System (Milestone, Italy) to undergo pressurized, microwave-assisted digestion (loading pressure: 40 bar; temperature ramped to 240°C). The digests were then quantitatively transferred to 50 mL polypropylene tubes and diluted to a final volume of 50 mL with ultrapure water. Diluted extracts were analysed directly for 15 trace elements and diluted 1:10 with ultrapure water and 0.2 mL nitric acid for the analysis of 5 minerals (Ca, K, Na, Mg, P).

Analysis

Digests were analysed using an Agilent 7900 inductively coupled plasma-mass spectrometry (ICP-MS) with octopole collision cell and Agilent SPS 4 autosampler, Appendix T2. The collision cell was pressured with 5 mL min^{-1} He gas to remove isobaric interferences and a ^{115}In internal standard (1 mg L^{-1}) was introduced continuously post-autosampler. The instrument was fitted with Ni sampler and skimmer cones. Element concentrations were determined using an external calibration series ranging from 0-100 µg L^{-1}. Limits of quantification ranged between 0.002-3.8 mg kg^{-1} for all trace elements and 1.6-27 mg kg^{-1} for minerals (Appendix T3).

Per and polyfluoroalkyl substances

Sample preparation

In triplicate, 0.75 g of freeze-dried egg material was weighed into 50 mL polypropylene tubes and reconstituted with 2.25 mL of water (LC grade). For feed samples 3 g of material was used without the addition of water. Samples were spiked with 50 µL of isotopically labelled internal standards (10 ng mL^{-1}; MPFAC-EIS) 3 and vortexed before the addition of 5 mL of acetonitrile. Sample mixtures were sonicated for 15 minutes and centrifuged (4000 rpm, 15 minutes). The supernatant was then removed, and the extraction repeated as before using the sample pellet.

The supernatants were then combined in a 50 mL pp falcon tube and cleaned using a dispersive solid phase extraction (dSPE) procedure, where 100 mg of C18 powder, 100 mg GCB, 500 mg of NaCl and 2 g of MgSO4 was added to the extract. The mixture was shaken vigorously for 1 minute before centrifugation (4000 rpm, 15 minutes). The supernatant was transferred to a 15 mL pp tube and evaporated to dryness at 50°C under a stream of nitrogen gas. Samples were reconstituted with 450 µL of mobile phase (4:1 v/v mobile phase A and B) and 50 µL of an injection standard (10 ng mL^{-1}; MPFAC-IS).

Analysis

Targeted analysis was carried out for 40 PFAS using liquid chromatography (Thermo Vanquish, fitted with Thermo PFC-free kit) coupled to a triple quadrupole mass spectrometer (Thermo TSQ Altis). Analytes were separated using a reverse phase Raptor C18 column (50 x 3mm; 2.7 µm) and a 5mM ammonium acetate in water and acetonitrile gradient (0.3 mL min^{-1}), Appendix T4. A delay column (50 x 4.6 mm; 1.9 µm) was additionally installed between the solvent mixer and injector. The mass spectrometer was used with a heated-electrospray ionisation source (H-ESI) and run in negative selected reaction monitoring (SRM) mode. The ion source voltage was -2500 V, and the ion transfer tube temperature was set to 325°C and the and vaporizer temperature to 300°C. Sheath gas, auxiliary gas and sweep gas were set to 50, 10 and 1 Arb, respectively. The concentrations of PFAS in samples was determined using the internal standard method, Appendix T5, and for compounds where no mass-labelled analogue was available, the closest eluting labelled standard was used. The branched isomer of PFOS was used for quantification of branched PFOS. The recovery of the mass-labelled internal standard was determined using the response of the injection standard (Appendix T5), where acceptable recoveries were between 30-200%. The limits of quantification ranged between 0.03-0.1 µg kg^{-1} for all compounds in egg and feed matrices and was validated through spiking and recovery experiments.

Where possible at least two mass transitions were monitored for each compound, Appendix T6, with the most intense transition being used for quantification. However, both PFBA and PFPeA have only one mass transition, therefore, the identity of these compounds was confirmed with retention time matching to the corresponding mass-

labelled internal standard/injection standard and the native standard used for calibration (Appendix F1). Additionally, a negative mode Q3 full scan was performed on parent masses 213 (PFBA) and 263 (PFPeA) to search for fragments arising from interferents eluting at the same retention time using several sample extracts (Appendix F2). Isobaric interferences from cholic acids on the mass transition 499 -> 80 m/z (PFOS) were resolved using the mobile phase gradient with acetonitrile.

Results and Discussion

Proximates

The proximate composition was generally similar across all eggs collected during the project, Figure 2, where protein content ranged from 11.5-12.8%, water content from 73.1-78.6% and lipid content from 8.3-12.6%. These values are in line with those previously reported for eggs produced in other areas of Europe such as the UK, France, Denmark and Germany (12). There were no clear differences in egg proximate composition between those laid by hens fed with regular and organic composite feeds (Flóahreppur vs. Vatnsleysustönd), and additionally no seasonal trends were observed between months. Products from Hrísey and independently produced eggs typically contained higher compositions of fat, perhaps due to the inclusion of leftover food in the diets of the laying hens which has been shown to improve egg quality (13). The proximate compositions expressed in alternative units (g/ 100g and g per egg) are presented in Appendices T7 and T8.

All feeds contained between 13.7-18.7% protein content, where organic feeds (organic 2 and organic 3) contained the highest levels of protein each sampling month. Water (8.4-11%) and lipid content (4.1-6.2%) were similar between all feeds. The ash content in feed organic 22 collected in January (28.8%) was more than double that of the other feeds (12.1-13.7%). Normal values for ash content of laying hen feed typically range from 7-12%, and levels significantly higher than this have been linked to urinary tract issues as well as bone and joint problems in growing poultry birds (14). All values are presented in Appendix T7.

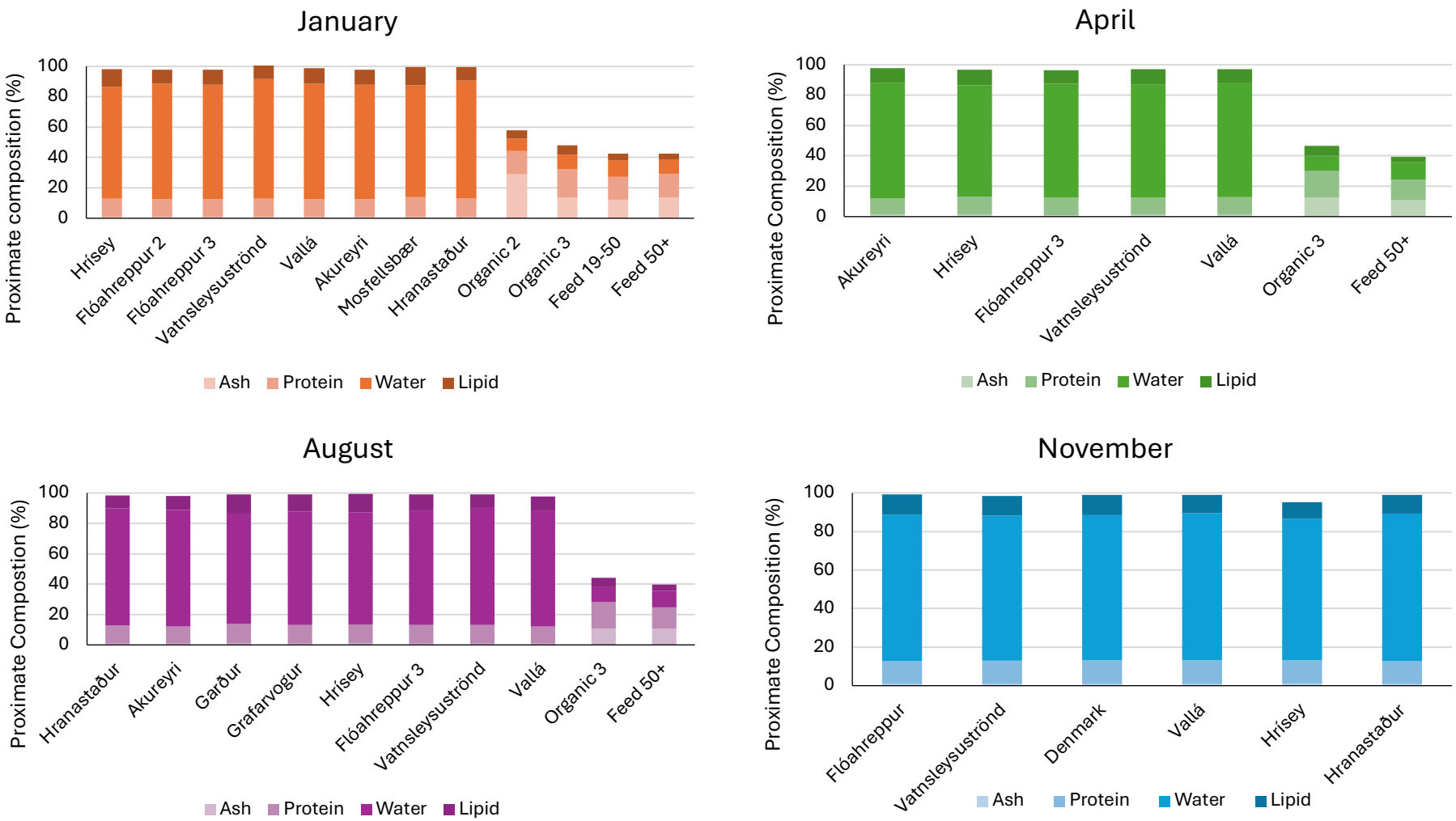

Figure 2. The ash, protein, moisture and lipid composition of egg and feed samples collected from producers in Iceland.

Fatty acid composition

The lipid fraction extracted from samples during proximate analysis was examined further detail to determine the composition of fatty acids. Monounsaturated fatty acids (MUFAs) were found to be most abundant class of lipids in eggs, Figure 3, whilst in feeds this was the polyunsaturated fatty acids (PUFAs). Oleic acid (C18:1) was the dominant fatty acid found in eggs followed by palmitic acid (C16:0) and lineoleic acid (C18:2), Appendix T9. These are typically the major fatty acids reported in poultry eggs across Europe (15,16) The oleic acid content per egg varied between 1.5-2.9 g and was dependent on egg size.

The highest serving of total Omega-3 per egg was found in products from Akureyri (110-124 mg), Hranastaður (95-120 mg) and those from an independent producer in Garður (28 mg). This was also true of the docosahexaenoic acid (C22:6) which ranged from 78-96 mg per egg for these producers.

The organic feed typically contained higher levels of total Omega-3, and this appeared to result in higher levels in organic eggs. Alpha-linoleic acid was also higher in organic eggs (28-67 mg per egg) than non-organic (20-27 mg per egg). The fatty acid profiles of samples are presented as g kg and mg per whole egg in Appendices T9 and T10.

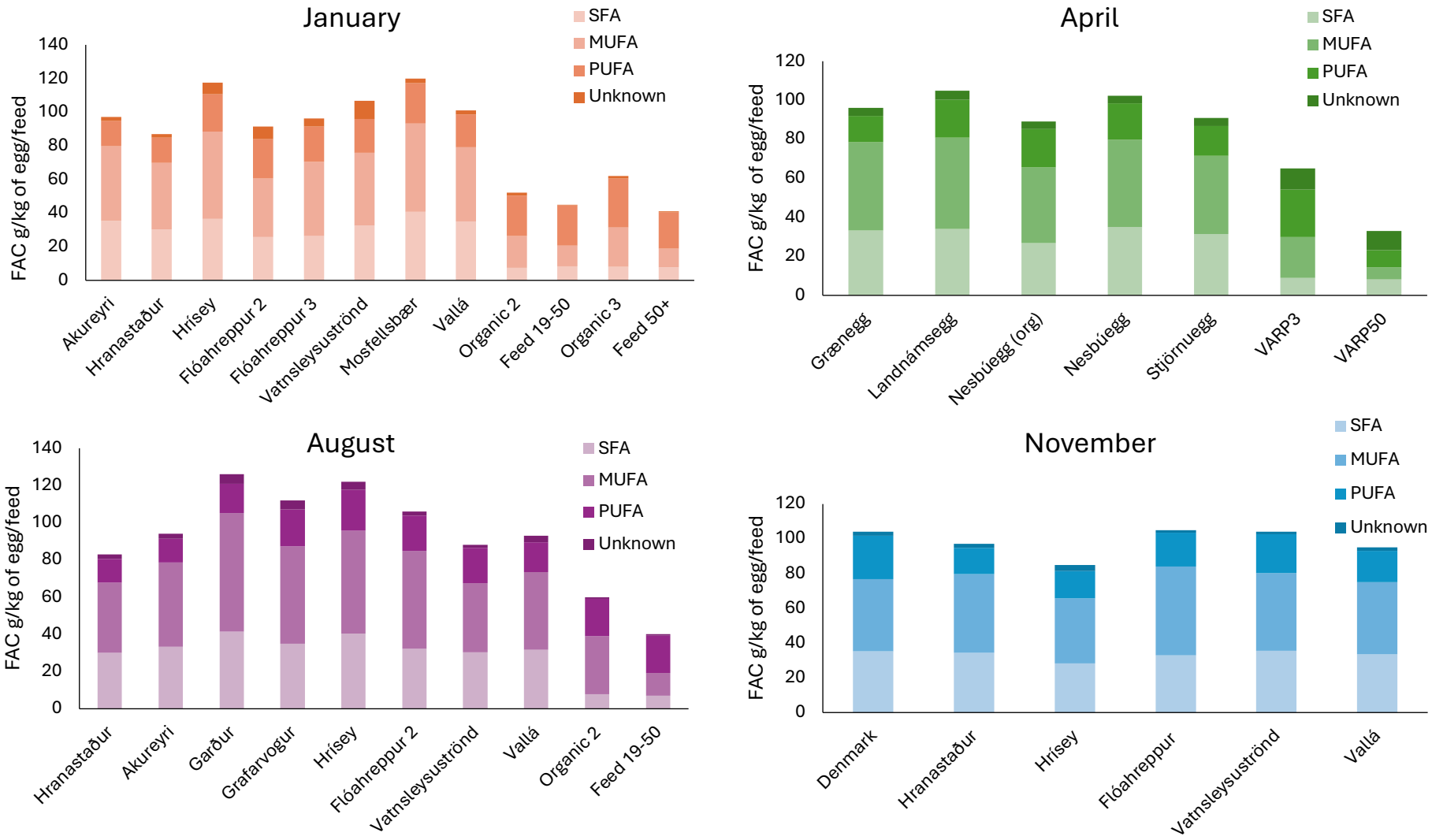

Figure 3. The saturated, mono-unsaturated and poly-saturated fatty acid content, and unknown lipid composition of egg and feed samples collected from producers in Iceland.

Table 2. The concentrations of major fatty acids detected in samples of egg and feed samples in g kg^{-1}.

Producer	Palmitic acid (C16:0)	Palmitoleic acid (C16:1)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid (C18:2)	Alpha-linolenic (C18:3)	Eicosenoic acid (C20:1)	Arachidonic acid (C20:4)	Docosahexaenoic acid (C22:6)
Hranastaður	22.1-24.5	2.0-2.4	7.6-9.4	35.6-42.6	10.7-11.8	0.31-0.33	0.19-0.22	1.2-1.3	1.6-1.7
Akureyri	23.9-25.5	2.2-2.5	8.9-9.5	41.7-42.7	11.2-11.8	0.32-0.40	0.22-0.29	1.2-1.3	1.4-1.5
Hrísey	20.0-29.3	1.4-2.6	7.9-10.7	36.0-52.3	12.6-19.7	0.33-0.60	0.20-0.32	1.6-2.3	0.77-1.2
Flóahreppur (organic)	18.8-25.0	1.1-1.7	6.3-7.6	33.3-50.6	15.4-19.4	0.53-1.2	0.16-0.27	1.2-1.8	0.89-1.0
Vatnsleysuströnd	22.1-26.1	1.5-2.0	7.9-9.8	35.1-42.5	15.6-18.6	0.41-0.47	0.22-0.31	1.5-1.8	0.82-0.92
Vallá	22.6-25.7	1.6-2.1	8.4-9.2	38.3-41.8	14.0-15.9	0.36-0.44	0.20-0.27	1.5-1.8	0.73-0.86
Independent producer (Grafavogur)	24.8	2	9.7	50	17.1	0.54	0.26	2.2	1.3
Independent producer (Garður)	31.2	3	9.5	60.5	12.54	0.74	0.23	2	1.9
Denmark	26.2	2.35	8.6	38.8	21.02	0.89	0.2	1.8	0.86
Mosfellsbær	30.5	2.4	10.1	49.7	18.61	0.46	0.24	2.3	0.84
Feed (organic)	5.4-6.9	0.0-0.13	1.5-1.8	18.3-30.8	18.1-25.4	1.7-3.7	0.27-0.85	-	0-0.03
Feed	5.9-7.0	0-0.08	0.92-1.1	5.8-11.7	8.0-22.5	0.46-1.5	0.22-0.36	-	0-0.10

Trace elements

The total concentrations of the 20 elements analysed in each sample are detailed in Appendices T11-12. Overall, the eggs produced in Iceland were found to be a valuable dietary source of trace elements such as iron (Fe), zinc (Zn) and selenium (Se). The organic feeds generally contained higher levels of trace elements than the regular feeds, however this did not result in vast differences between products and variation was greatest between months.

The concentrations of vanadium (V), cobalt (Co), nickel (Ni) and chromium (Cr) were below the limit of quantification for all egg samples analysed,Table 3. There were no clear trends in Manganese (Mn), Se or Zn concentrations, which all varied between months and producers. The eggs collected from the two independent producers (Grafarvogur and Garður) had the highest levels of Fe (24.6-21.3 mg kg^{-1}) and copper (Cu) (0.89-1.0 mg kg^{-1}) but it is unclear if this is due to differences in environmental conditions in comparison to commercial producers, or to differences in diets. Organic egg products were typically higher in molybdenum (Mo) likely due to the feed, as the average Mo content of the organic feed was approximately double that of the average regular feed.

Table 3. The range of concentrations of trace elements (V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Se and Mo) detected in all samples of egg and feed in mg kg^{-1}. The minimum, median and maximum values are shown.

	Egg			Feed		
Trace element	Min	Median	Max	Min	Median	Max
Vanadium (mg kg^{-1})	<LOQ	<LOQ	<LOQ	0.185	1.98	2.94
Chromium (mg kg^{-1})	<LOQ	<LOQ	<LOQ	0.511	3.91	12.0
Manganese (mg kg^{-1})	0.258	0.425	0.592	102	145	202
Iron (mg kg^{-1})	13.1	18.8	31.3	101	518	709
Cobalt (mg kg^{-1})	<LOQ	<LOQ	<LOQ	0.104	0.441	0.830
Nickel (mg kg^{-1})	<LOQ	<LOQ	<LOQ	0.747	2.55	8.11
Copper (mg kg^{-1})	0.466	0.606	1.00	15.2	19.3	31.2
Zinc (mg kg^{-1})	9.42	16.0	23.5	69.7	106	175
Selenium (mg kg^{-1})	0.170	0.259	0.462	0.292	0.357	0.710
Molybdenum (mg kg^{-1})	0.034	0.054	0.133	0.692	1.19	2.38

Toxic elements

The concentrations of toxic elements were generally low in all egg samples collected throughout the project, Table 4. Arsenic (As) was below the quantification limit in all samples except those from Akureyri and Hranastaður which are both located in the North of Iceland, where concentrations ranged from 0.02-0.03 mg kg^{-1}. These samples also contained the highest levels of mercury (Hg). However these values are still low for free-range hens, and are similar to previously reported for farms in Italy (17). Cadmium (Cd) and tin (Sn) concentrations in eggs were <LOQ and <0.003 mg kg^{-1} respectively.

All egg samples contained <0.01 mg kg^{-1} of lead (Pb) with the exception of those collected from independent producer 2 (Garður) which contained 0.07 mg kg^{-1} of Pb – approximately 7-fold higher than the sample with the next highest concentration. This is similar to home produced eggs in Massachusetts, US where the mean concentration of Pb was found to 0.10 mg kg^{-1} (18). Whilst the concentration reported here is low compared to what is typically ingested from other food source, the elevated levels compared to other locations in Iceland suggest there is an issue with contamination in areas surrounding the airport. Additionally, looking only at the concentrations found in eggs may not give an accurate representation of the problem as Pb is most accumulative in the internal organs and bones of organisms (19). The levels of toxic elements in all of the feeds analysed were well below the maximum limits set by EU directive 2002/32/EC for heavy metals in complete feeds (As – 2.0 mg kg^{-1}, Cd – 0.5 mg kg^{-1}, Hg – 0.1 mg kg^{-1}, Pb – 5.0 mg kg^{-1}).

Table 4. The concentrations of toxic elements (As, Cd, Hg and Pb) detected in all samples of egg and feed in mg kg^{-1}. The minimum, median and maximum values are shown.

	Egg			Feed		
Toxic Element	Min	Median	Max	Min	Median	Max
Arsenic (mg kg^{-1})	<LOQ	<LOQ	0.033	0.062	0.215	0.709
Cadmium (mg kg^{-1})	<LOQ	<LOQ	<LOQ	0.049	0.167	0.226
Mercury (mg kg^{-1})	<LOQ	<LOQ	0.030	<LOQ	<LOQ	<LOQ
Lead (mg kg^{-1})	<LOQ	<LOQ	0.070	0.120	0.304	0.507
Tin (mg kg^{-1})	<LOQ	<LOQ	0.003	0.010	0.025	0.073

The chemical form of the arsenic present was investigated during the first sampling in January 2024, in order to determine if carcinogenic inorganic arsenic (iAs) was measured in samples of egg and feed collected in January. Briefly, the concentrations of iAs were low in all organic feed 0.08-0.10 mg kg^{-1} and regular feed (0.024-0.028 mg kg^{-1}) samples, therefore this contaminant was not investigated in further samples. The extraction method and instrumental parameters for analysis are outlined in Appendix T13.

Minerals

The composition of minerals (Table 5) did not differ significantly between producers, or from that reported in literature from the UK and US (20,21). There were no distinct differences in mineral composition between organic and regular eggs from the same producer (Flóahreppur vs Vatnsleysuströnd) despite the organic feed generally having higher mineral content, Appendix T11. The mineral content of eggs varied month by month for producers in Hrísey and Akureyri however no clear trend could be identified - likely due to different ages of the hens used by each producer as the project progressed.

Table 5. The range of concentrations of minerals (Ca, K, Mg, Na and P) detected in all samples of egg and feed in mg kg^{-1}. The minimum, median and maximum values are shown.

	Egg			Feed		
Mineral	Min	Median	Max	Min	Median	Max
Calcium (mg kg^{-1})	405	519	608	21770	33830	75140
Potassium (mg kg^{-1})	881	1173	1364	5285	6436	7174
Magnesium (mg $kg^{-1)}$	89	120	145	1307	2095	3831
Sodium (mg kg^{-1})	1014	1218	1577	1044	1424	1844
Phosphorous (mg kg^{-1})	1486	2037	2357	3305	4553	6467

Per- and polyfluoroalkyl substances

40 different PFAS were analysed in samples collected during the project and these compounds are often further categorised into several groups based on their structure. These groups can include polyfluorinated sulphonates, polyfluorinated carboxylic acids, fluorotelemers, perfluoroalkane sulfonamides and perfluoroalkyl ether acids.

The most well-known **polyfluorinated sulphonate** is PFOS, which has a fully fluorinated 8-carbon chain attached to a sulphonate group, Figure 4. The compounds analysed in this study have carbon chain lengths ranging from C4 (PFBS) to C12 (PFDoS).

Polyfluorinated carboxylic acids also have a fully fluorinated carbon chain, however the end group is comprised of a carboxylic acid group, Figure 4. Both PFOA (C8) and PFNA (C9) are polyfluorinated carboxylic acids.

The **fluorotelomers** analysed during this project include fluorotelomer sulphonates (4:2FTS, 6:2FTS and 8:2FTS) and fluorotelomer carboxylic acids (i.e., 3:3FTCA, 5:3FTCA and 7:3FTCA). They contain a fluorinated carbon chain, but the end group is attached via an ethylene linkage, Figure 4.

Perfluoroalkane sulfonamides can be used to describe compounds such as PFOSA, N-MeFOSA and N-MeFOSAA. Sulfonamidoethanols were also analysed (N-MeFOSE and N-EtFOSE).

Perfluoroalkyl ether acids are a group of emerging compounds including ADONA and Gen X. These compounds contain an ether linkage, and F53-B compounds (major and minor) also contain one chlorine atom.

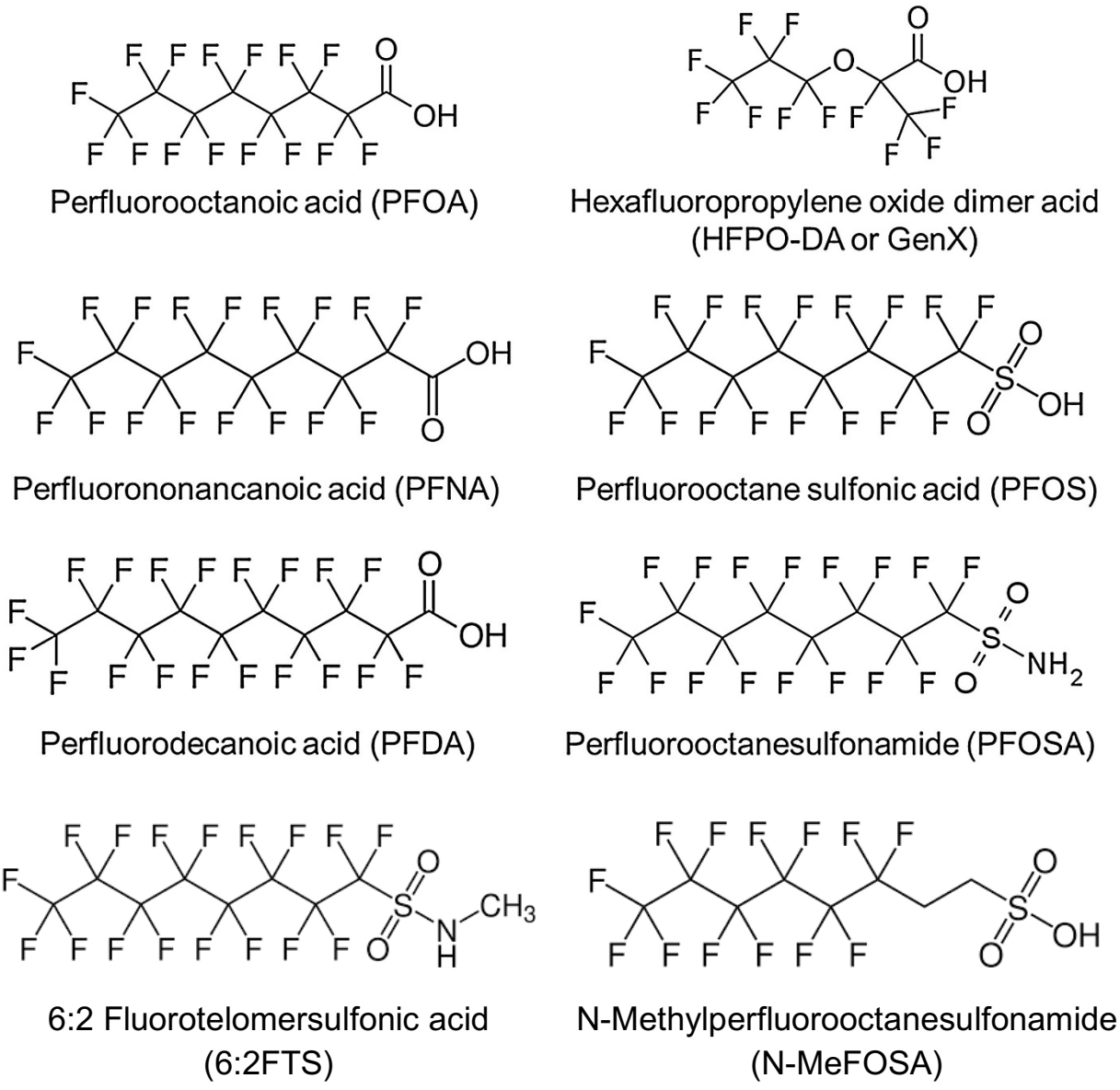

Figure 4. The structure of several different classes of PFAS.

Regulated PFAS (PFOS, PFOA, PFNA and PFHxS)

Maximum levels for PFOS, PFOA, PFNA and PFHxS (and their sum) in eggs are currently outlined in Commission Regulation (EU) 2023/915. Concentrations of the regulated PFAS were generally low in the samples analysed, and only one egg sample was found to exceed these maximum levels, specifically for PFOS where the concentration was 1.47 μg kg^{-1} compared with the EU limit of 1.0 μg kg^{-1}. In addition, this sample was found to contain PFOA (0.03 μg kg^{-1}), PFNA (0.10 μg kg^{-1}) and PFHxS (0.07 μg kg^{-1}), however the sum of the four did not exceed the EU limit of 2.0 μg kg^{-1}. This sample was collected during August from an independent farm (Garður) that produces eggs for personal consumption, and the high levels found here are likely due to the proximity to the international airport (~10 km). Airports are a known to release significant levels of PFAS contamination into the surrounding environment due to the use of fire-fighting foams which may remain in the surrounding soils and ground water for decades (22). Another egg sample collected from hens kept in Njarðvík (~5 km from international airport) also showed elevated levels of PFOS (0.23 μg kg^{-1}). However, this sample was collected in February during winter so it is likely the hens will have spent more time indoors than those from which eggs were collected from in Garður in August, as ingestion of contaminated soil through pecking is thought to be a major exposure pathway for laying hens and broilers (23). The concentration of PFOS in all other eggs collected during the project ranged from <LOQ-0.19 μg kg^{-1}.

The concentrations of PFOA in all egg samples were ≤0.03 μg kg^{-1}, Table 6, and levels of PFNA ranged from <LOQ-0.10 μg kg^{-1} and PFHxS from <LOQ-0.07 μg kg^{-1}. PFOS was the most frequently detected of the four regulated PFAS (14 egg samples) which is in line with what has previously been reported for both commercial and home produced eggs (24), albeit in much lower concentrations. None of the four regulated PFAS were detected in any of the feed samples.

Table 6. The range of concentrations of PFOS, PFOA, PFNA and PFHxS in egg samples collected during the project. None of the four regulated PFAS were detected in any of the feed samples.

		Egg	
Analyte	Min	Median	Max
PFOS	<LOQ	<LOQ	1.47
PFOA	<LOQ	<LOQ	0.03
PFNA	<LOQ	<LOQ	0.10
PFHxS	<LOQ	<LOQ	0.07

Other polyfluorinated carboxylic acids (C4-C14)

There were no seasonal or producer specific trends, however polyfluorinated carboxylic acids were most abundant in the samples collected in Garður.

PFPeA, PFHxA and PFHpA were not detected in any samples. PFDA was above the detection limit in 6 samples, where concentrations ranged from 0.03-0.09 μg kg^{-1}. PFUndA was found in 5 samples at levels between 0.05-0.12 μg kg^{-1} and PFDoA was detected in 2 samples of egg (0.06-0.23 μg kg^{-1}) and 2 samples of feed collected in August (0.10 μg kg^{-1}). PFTrDA was detected 2 samples (0.06-0.17 μg kg^{-1}) and PFTeDA was only detected in the egg sample from Garður (0.27 μg kg^{-1}).

PFBA concentrations were above the quantification limit in 6 samples where concentrations ranged from 0.10-0.15 μg kg^{-1}. This compound could not be accurately quantified in the samples from the years 2016, 2020 and 2022 due to the presence of a large unknown peak that could not be fully chromatographically resolved from the PFBA peak, Appendix F3. A saturated oxo-fatty acid with the same parent mass and mass transition (213 m/z ->169 m/z) has been previously identified as an interferent that is widespread in biological matrices (25). The elevated levels that were not removed during sample clean up are perhaps due to oxidative deterioration of larger lipids during storage over many years (26).

Other polyfluorinated sulphonates (C4-C10)

PFBS, PFPeS, PFHpS and PFNS were not detected in any samples. PFDS and PFDoS were detected in one egg sample collected at Garður from an independent producer at concentrations of 0.20 μg kg^{-1} and 0.05 μg kg^{-1} respectively.

Emerging PFAS

Gen X, ADONA, PFMPA, PFMBA, NFDA, PFOSA, F-53B (major and minor), 3:3FTCA, 5:3 FTCA, 7:3FTCA, 4:2FTS, 8:2FTS, N-MeFOSA, N-EtFOSA, N-MeFOSAA, N-EtFOSAA, N-EtFOSE and N-MeFOSE were below the detection limits in all samples. The fluorotelemer 6:2 FTS was detected in all feed samples collected in January, where concentrations ranged from 0.10-0.13 μg kg^{-1}. This compound is commonly found in food contact materials such as a plastic bags and plastic-coated cardboard but not feed (27,28), so is likely to have arisen from the packaging material rather than the feed itself. The migration of PFAS into feed from contaminated packaging materials should be investigated further as feed products are typically sold with shelf lives that may be several months long.

Temporal trends

Preserved samples from the years 2016, 2020 and 2022 were included in the analysis to observe potential temporal trends in PFAS contamination. The levels of all four regulated PFAS have been consistently low in eggs from Akureyri, Hrísey, Vatnsleysustönd and Vallá. PFOS concentrations were all <0.09 ug kg^{-1} which is well below the EU maximum limit of 1.0 µg kg^{-1}. As for the other regulated compounds, samples contained ≤0.03 µg kg^{-1} of PFOA and PFNA, and PFHxS levels were all ≤0.05 µg kg^{-1}. PFUnDA was detected in Akureyri 2022 and Vallá 2016 samples with concentrations ranging from 0.06-0.09 µg kg^{-1}. PFDA was also detected in the Vallá sample from 2016 (0.03 µg kg^{-1}).

Estimated weekly intake of total PFAS from eggs

The lower bound concentrations were used to estimate the weekly exposure of Icelandic consumers to PFAS through the consumption of egg products, Table 7. The lower bound concentrations were used for the estimation, as the large number of compounds analysed here would result in inflated concentrations (i.e., from 2.64-4.75 µg kg^{-1}), as for upper bound calculations the quantification limit is assigned as the concentration for compounds <LOQ. The estimates were also based on equipotency – the assumption that all PFAS are equally toxic.

The average Icelander across all age groups consumes approximately 140 g of egg per week according to the 2019-2021 National Dietary Study (29). However, consumption across different age demographics in Iceland is not available, therefore freely accessible statistical data on egg consumption from another European country (Netherlands) was used to estimate the weekly intake across different age groups (30). Consumers aged 1-3 years were assumed to have mean intake of 49.7 g per week and 95th percentile intake of 289 g per week (0.99-5.8 medium eggs), and consumers aged 18-79 years were assumed to have a mean intake of 126 g per week and 95th percentile intake of 502 g per week (2.5-10 medium eggs). It should be noted that eggs consumed as ingredients in other foods, i.e., baked goods, were not included this estimation.

The European Food Safety Authority has defined a safe tolerable weekly intake of 4.4 ng of PFAS per kg of body weight (8). The consumption of the average home-produced eggs from this study would contribute between 51-203% of the weekly PFAS exposure limit for a 60 kg adult, whilst the average commercially produced egg would only account for 3-12%. For a child weighing 10 kg home-produced eggs would contribute 121-705% of weekly PFAS intake compared to 7-40% for commercially produced products. Commercially produced eggs contribute vastly less to PFAS exposure and are therefore safer for children due to their lower body masses and those who consume a large number of eggs per week, such as vegetarians.

Table 7. The weekly exposure intake of PFAS from consumption of commercial and home-produced eggs. Values were calculated based on mean and 95th percentile weekly consumption of eggs for age groups 1-3 years and 18-79 years, and average and maximum lower bound sum of PFAS for commercial and home-produced eggs.

		Commercial eggs (ng per week)		Home-produced eggs (ng per week)	
Age group (years)	Weekly Intake (g)	mean: 0.06 μg kg^{-1}	max: 0.26 μg kg^{-1}	mean: 1.07 μg kg^{-1}	max: 2.70 μg kg^{-1}
1-3	49.7 (mean)	3.01	12.8	53.3	134
	289 (95th)	17.5	74.4	310	781
18-79	126 (mean)	7.63	32.4	135	340
	502 (95th)	30.4	129	538	1356

Conclusion

The PFAS levels in Icelandic and imported Danish eggs were well below EU maximum levels for all commercially produced eggs analysed, including those from the years 2016-2022. However, home produced eggs collected near Keflavík (Garður) contained high levels of PFAS which exceeded maximum levels for PFOS during the Summer. This contamination can likely be traced back to Keflavík international airport where PFAS-containing firefighting foams may have been used previously. There were no direct links between the levels of PFAS found in feed and eggs, and the degree of contamination is more likely linked to the location where hens are kept and the length of time spent outdoors. From these results we can conclude that the inclusion of fishmeal in laying hen feed did not increase PFAS levels in the eggs.

Eggs produced in Iceland were rich in essential trace elements (Fe, Zn and Se), minerals (Na, Mg, P, K and Ca), unsaturated fatty acids and Omega-3, and are an important protein source for nearly all demographics of consumers. Commercially produced eggs were also low in heavy metals, however, relatively high levels of Pb were detected in home-produced egg samples collected near Keflavík and concentrations were approximately seven times higher than all other samples.

These results have confirmed that free-range Icelandic eggs and the majority of home-produced eggs are safe for consumers. Commercial eggs are safest for children and those who consume high numbers of eggs per week. These results could prompt further expansion of commercial egg production in Iceland, which would in turn would reduce the reliance on imported sources for during shortages or for industries such as hospitality. This important work may also lead to further investigation of PFAS and Pb contamination arising from Keflavík airport and how this may be impacting the health of those living in this area.

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Appendix

Appendix T1. The pooling of preserved egg samples from a previous monitoring project during the years 2016, 2020 and 2022. Samples that were collected from different months of the year were pooled and homogenised to create a representative sample from producers during each year.

Producer location	2016	2020	2022
Akureyri	November	September	June December
Hrísey	-	June	December
Vatnsleysuströnd	November	June September	May September December
Vallá	November	June September	May September December

Appendix T2. The instrumental parameters for the analysis of total element concentration using an Agilent 7900 ICP-MS and Agilent SPS 4 autosampler.

ICP-MS operating conditions	
RF power	1550 W
RF matching	1.20 V
Plasma gas	15 L min^{-1}
Carrier gas	1.07 L min^{-1}
Make-up gas	0.80 Lmin^{-1}
Spray chamber temperature	2°C
Octopole collision cell	Pressurized, He gas (5 mL min^{-1})
Integration time	1000 ms
Peak pattern	3
Replicates per analysis	3
Isotopes monitored	Na^{23}, Mg^{24}, P^{31}, K^{39}, Ca^{44}, V^{51}, Cr^{52}, Mn^{55}, Fe^{56}, Co^{59}, Ni^{60}, Cu^{63}, Zn^{66}, As^{75}, Se^{78}, Mo^{95}, Cd^{111}, In^{115}*, Sn^{118}, Hg^{202} Pb^{208}

*Internal standard.

Appendix T3. The limit of detection and limit of quantification for analysis of total element concentration by ICP-MS.

	Limit of Detection (mg kg^{-1})	Limit of Quantification (mg kg^{-1})
V	0.02	0.07
Cr	0.02	0.05
Mn	0.02	0.05
Fe	0.4	1.2
Co	0.003	0.01
Ni	0.02	0.05
Cu	0.01	0.04
Zn	1.2	3.8
As	0.006	0.02
Se	0.06	0.2
Mo	0.004	0.01
Cd	0.003	0.01
Sn	0.001	0.002
Hg	0.007	0.02
Pb	0.003	0.01
Na	2.4	7.9
Mg	0.48	1.6
P	8.1	26.6
K	6.4	21.2
Ca	3.8	12.5

The limit of detection was calculated as the standard deviation of 5 procedural blanks multiplied by 3. The limit of quantification was calculated as the standard deviation of 5 procedural blanks multiplied by 10.

Appendix T4. The instrumental parameters for the analysis of 40 PFAS using a Thermo Vanquish LC and Thermo TSQ Altis qqq-MS.

LC-MS/MS operating conditions	
Analytical column	Restek C18, 50 x 3.0 mm, 2.7 µm
Delay column	Thermo Hypersil Gold C8, 50 x 4.6 mm, 1.9 µm
Mobile phase	A: 5 mM Ammonium acetate in water
	B: Acetonitrile
Mobile phase gradient	0.0 min 20% B
	2.5 min 45% B
	6.5 min 70% B
	9.0-12.0 min 100% B
	12.1-17.5 min 20% B
Injection volume	5 µL
Flow rate	0.3 mL min^{-1}
Ion source	2500 V
Ion transfer tube temperature	325°C
Vaporizer temperature	300°C
Sheath gas	50 Arb.
Auxiliary gas	10 Arb.
Sweep gas	1 Arb.

Appendix T5. The limit of quantification for analysis of PFAS concentrations by LC-MS/MS as well as the specific internal and injection standards used for each compound.

Abbreviation	Internal Standard	Injection Standard	LOQ µg kg^{-1}
PFBA	^{13}C - PFBA	M3PFBA	0.1
PFPeA	$^{13}C_5$ – PFPeA	M3PFBA	0.05
PFHxA	$^{13}C_5$ – PFHxA	MPFHxA	0.05
PFHpA	$^{13}C_4$ – PFHpA	MPFOA	0.05
PFOA	$^{13}C_8$ – PFOA	MPFOA	0.03
PFNA	$^{13}C_9$ – PFNA	MPFNA	0.03
PFDA	$^{13}C_6$ – PFDA	MPFDA	0.03
PFUdA	$^{13}C_7$ – PFUdA	MPFDA	0.05
PFDoA	^{13}C – PFDoA	MPFDA	0.05
PFTrDA	$^{13}C_2$ – PFTeDA	MPFDA	0.05
PFTeDA	$^{13}C_2$ – PFTeDA	MPFDA	0.05
PFBS	$^{13}C_3$ – PFBS	MPFHxS	0.05
PFPeS	$^{13}C_3$ – PFHxS	MPFHxS	0.05
PFHxS	$^{13}C_3$ – PFHxS	MPFHxS	0.05
PFHpS	$^{13}C_8$ – PFOS	MPFOS	0.05
PFOS	$^{13}C_8$ – PFOS	MPFOS	0.05
PFNS	$^{13}C_8$ – PFOS	MPFOS	0.05
PFDS	$^{13}C_8$ – PFOS	MPFOS	0.05
PFDoS	$^{13}C_8$ – PFOS	MPFOS	0.05
4:2FTS	$^{13}C_2$ – 4:2FTS	MPFOS	0.1
6:2FTS	$^{13}C_2$ – 6:2FTS	MPFOS	0.1
8:2FTS	$^{13}C_2$ – 8:2FTS	MPFOS	0.1
PFOSA	$^{13}C_8$ – PFOSA	MPFOS	0.1
N-MeFOSA	d_3 - N-MeFOSAA	MPFOS	0.1
N-EtFOSA	d_5 - N-EtFOSAA	MPFOS	0.1
N-MeFOSAA	d_3 - N-MeFOSAA	MPFOS	0.1
N-EtFOSAA	d_5 - N-EtFOSAA	MPFOS	0.1
N-MeFOSE	d_3 - N-MeFOSAA	MPFOS	0.1
N-EtFOSE	d_5 - N-EtFOSAA	MPFOS	0.1
HFPO-DA (Gen X)	$^{13}C_9$ – PFNA	MPFNA	0.05
ADONA	$^{13}C_9$ – PFNA	MPFNA	0.05
PFMPA	$^{13}C_9$ – PFNA	MPFNA	0.05
PFMBA	$^{13}C_9$ – PFNA	MPFNA	0.05
NFDHA	$^{13}C_9$ – PFNA	MPFNA	0.05
9Cl-PF3ONS (F-53B major)	$^{13}C_9$ – PFNA	MPFNA	0.05
11Cl-PF3OUdS (F-53B minor)	$^{13}C_9$ – PFNA	MPFNA	0.05
PFEESA	$^{13}C_9$ – PFNA	MPFNA	0.05

3:3FTCA	$^{13}C_9$ – PFNA	MPFNA	0.1
5:3FTCA	$^{13}C_9$ – PFNA	MPFNA	0.1
7:3FTCA	$^{13}C_9$ – PFNA	MPFNA	0.1

The limit of quantification was determined by multiplying the lowest calibration point for each compound by an average dilution factor.

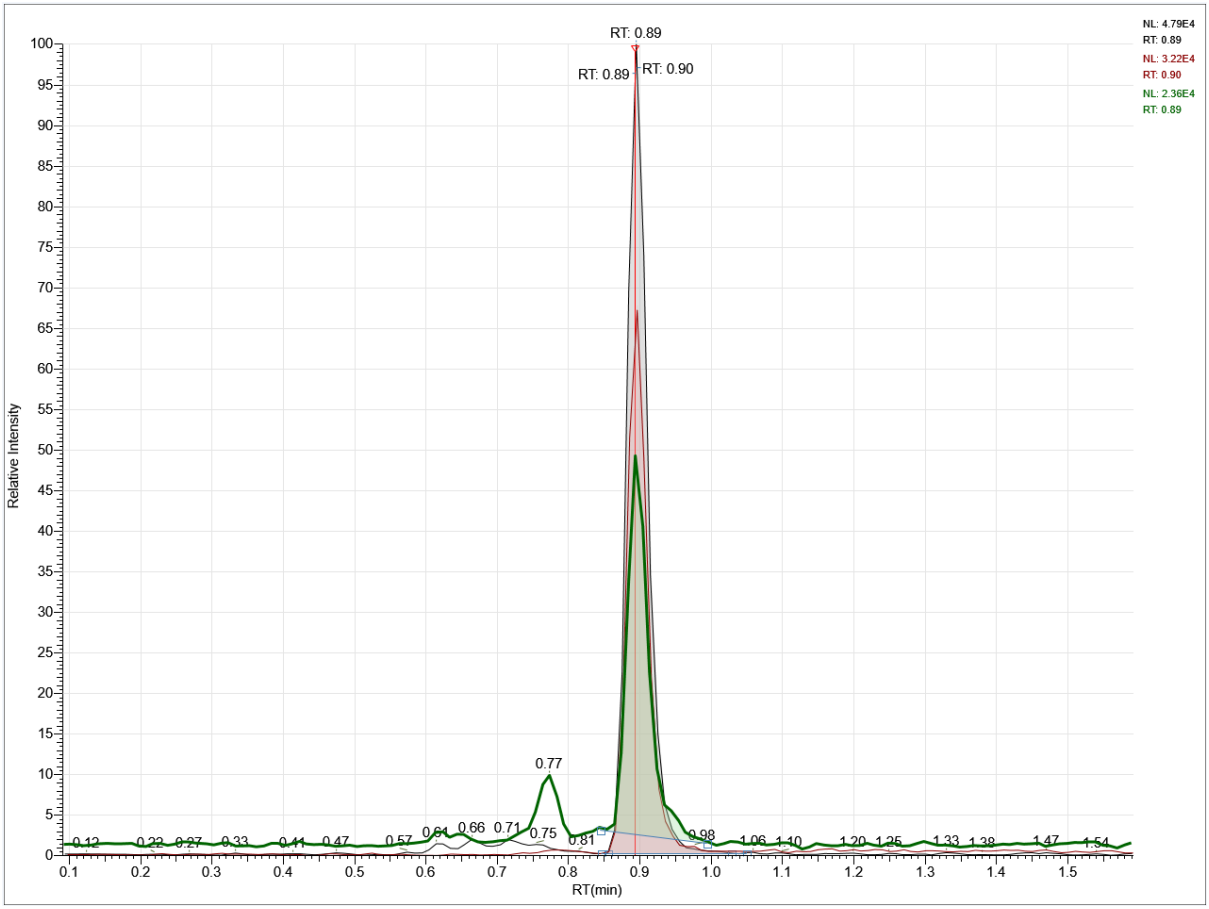
Appendix T6. The quantitative and confirmative mass transitions, retention time and source parameters used for the analysis of PFAS in eggs and feed using LC-MS/MS.

Compound	Retention time (min)	Precursor (m/z)	Products (m/z)	Collision Energy (V)	RF Lens (V)
PFBA	0.91	213	169	9	30
PFPeA	1.59	263	219	9	31
PFHxA	5.37	313	269*	9	39
			119	18.76	39
PFHpA	6.75	363	319*	9	43
			169	15.53	43
			119	19.52	43
PFOA	7.23	413	369*	9	49
			219	14.55	49
			169	16.1	49
PFNA	7.62	463	419*	9	52
			219	15.23	52
			169	17.51	52
PFDA	8.04	513	469*	9	56
			269	15.8	56
			219	16.14	56
PFUdA	8.44	563	519*	17.32	62
			269	17.32	62
			219	17.32	62
PFDoA	8.96	613	569*	9	67
			319	17.54	67
			169	23.69	67
PFTrDA	9.44	663	619*	9	71
			369	17.85	71
			169	25.16	71
PFTeDA	9.96	713	669*	9	74
			369	18.87	74
			169	19.86	74
PFBS	5.34	299	80*	34	116
			99	29	116
PFPeS	6.93	349	80*	33.66	115
			99	31	115
PFHxS	7.40	399	80*	39	135
			99	35	135
PFHpS	7.82	449	80*	37.6	131
			99	36.2	131
PFOS	8.32	499	80*	47	159
			99	40	159

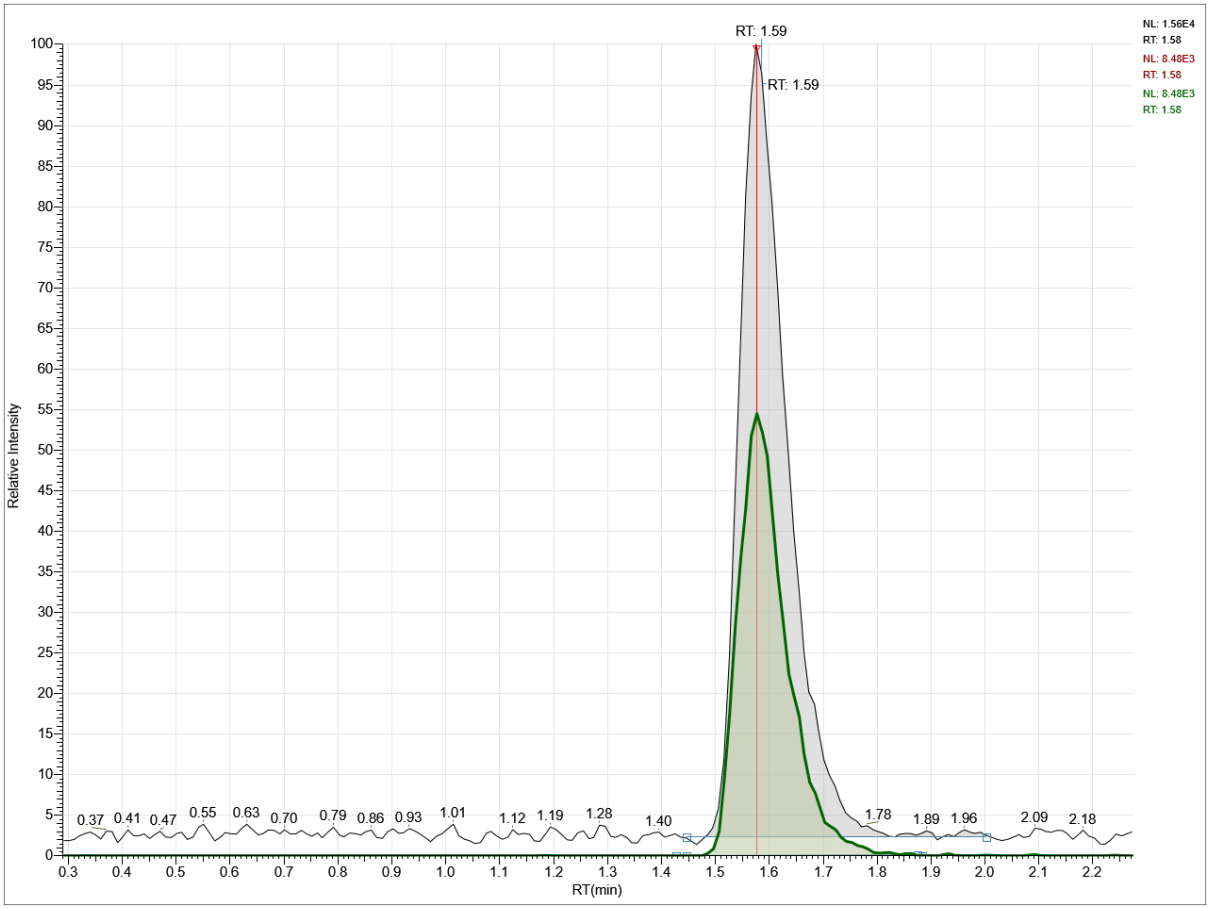
PFNS	8.79	549	80*	42.34	148
			99	40.67	148
PFDS	9.28	599	80*	44.92	169
			99	43.48	169
PFDoS	10.29	699	80*	53	190
			99	48	190
4:2FTS	3.71	327	81*	26.07	115
			287	23	115
			307	18.11	115
6:2FTS	7.05	427	81*	29.94	123
			387	26.72	123
			407	21.45	123
8:2FTS	7.83	527	81*	34.83	137
			487	28.92	137
			507	24.37	137
PFOSA	10.01	498	78*	29.37	127
			169	25.85	127
			478	22.51	127
N-MeFOSA	11.73	512	219*	24	130
			169	26	130
N-EtFOSA	12.11	526	219*	20	107
			169	20	107
N-MeFOSAA	8.08	570	512*	19.55	107
			483	14.06	107
			419	18.42	107
N-EtFOSAA	8.27	584	526	18.26	101
			483	13.9	101
			419	18.24	101
N-MeFOSE	11.56	616	59	16	68
N-EtFOSE	11.95	630	59	16	65
HFPO-DA (Gen X)	6.17	285	169*	7	25
			85	17	25
ADONA	6.96	377	251*	10	46
			85	22	46
PFMPA	1.04	229	185*	7	31
			85	10.5	31
PFMBA	2.25	279	235*	7.5	38
			85	10.5	38
NFDHA	4.99	295	85	22	33
			201*	8	33
9Cl-PF3ONS (F-53B major)	8.64	531 533	351* 353	25 25	130 130

11Cl-PF3OUdS (F-53B minor)	9.63	631 633	451* 453	27 27	140 140
PFEESA	6.38	315	83 135*	19 22	60 60
3:3FTCA	1.02	241	117 177*		
5:3FTCA	6.34	341	217 237*	25 13	42 42
7:3FTCA	7.54	441	317 337*	20 11	46 46

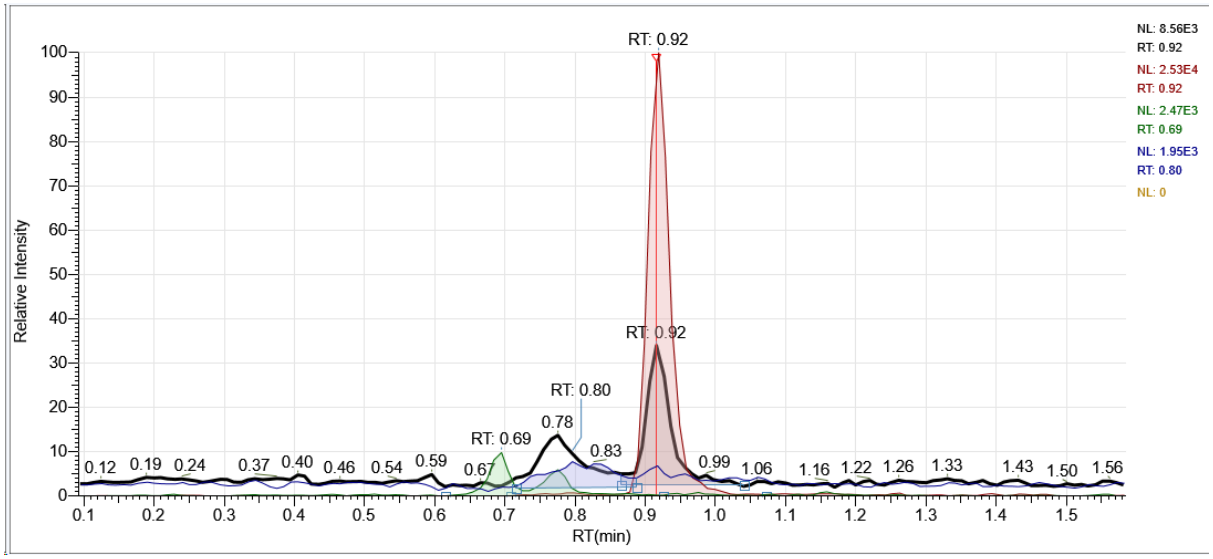
*Mass transition used for quantification.



Appendix F1a. An extracted ion chromatograph showing a sample spiked with 0.5 ng mL^{-1} of native PFBA (green), 1 ng mL^{-1} of isotopically labelled PFBA internal standard (red) and 1 ng mL^{-1} of isotopically labelled PFBA injection standard (grey).



Appendix F1b. An extracted ion chromatograph showing the retention time overlap of the native PFPeA standard (0.5 ng mL^{-1}) and the isotopically labelled PFPeA internal standard (1 ng mL^{-1}).



Appendix F2. Extracted ion chromatographs of the mass fragments detected around the retention time of PFBA during a Q3 scan for parent ion 213 m/z. The mass transition for the isotopically labelled PFBA standard is shown in red and the mass transition used for the quantification of PFBA (213->169 m/z) is shown in black.

Appendix T7. The proximate compositions of eggs and feed samples collected throughout the duration of the project in g/ 100g sample.

Month	Sample	Type	Ash (g/ 100 g)	Protein (g/ 100 g)	Water (g/ 100 g)	Lipid (g/ 100 g)
Jan	Hrísey	egg	1.0	12.0	73.5	11.7
	Flóahreppur 2	egg	1.0	11.5	76.3	9.1
	Flóahreppur 3	egg	1.0	11.5	75.6	9.6
	Vatnsleysuströnd	egg	1.0	12.0	78.6	10.7
	Organic 2	feed	28.8	15.4	8.4	5.2
	Feed 19-50	feed	12.1	15.1	11	4.5
	Organic 3	feed	13.7	18.7	9.4	6.2
	Feed 50+	feed	13.6	15.5	9.3	4.1
	Vallá*	egg	1.0	11.7	75.9	10.1
	Akureyri*	egg	0.9	11.5	75.7	9.7
	Mosfellsbær*	egg	1.0	12.8	73.7	12
	Hranastaður*	egg	0.9	12.2	77.5	8.7
April	Akureyri	egg	1.1	11.1	75.9	9.6
	Hrísey	egg	1.1	12.2	73.1	10.5
	Flóahreppur 3	egg	1.0	11.5	75.1	8.9
	Vatnsleysuströnd	egg	1.2	11.4	74.3	10.2
	Vallá	egg	1.1	11.8	75	9.1
	Organic 3	feed	12.4	17.7	9.9	6.5
	Feed 50+	feed	10.9	13.7	11.5	3.3
Aug	Hranastaður	egg	0.9	12.0	77.1	8.3
	Akureyri	egg	0.9	11.1	76.8	9.4
	Garður	egg	1.1	12.8	72.7	12.6
	Grafarvogur	egg	0.9	12.1	74.8	11.2
	Hrísey	egg	1.1	12.4	73.6	12.2
	Flóahreppur 3	egg	1.0	12.1	75.4	10.6
	Vatnsleysuströnd	egg	0.9	12.3	77.1	8.8
	Vallá	egg	1.0	11.0	76.4	9.3
	Organic 3	feed	10.8	17.4	9.9	6.0
	Feed 50+	feed	10.6	14.2	10.8	4.0
Nov	Flóahreppur	egg	1.0	11.6	76.1	10.5
	Vatnsleysuströnd	egg	1.0	12.0	75.1	10.4
	Denmark	egg	1.0	12.1	75.4	10.4
	Vallá	egg	1.0	12.1	76.4	9.5
	Hrísey	egg	1.1	12.0	73.5	8.5
	Hranastaður	egg	1.0	11.8	76.5	9.7

*Collected in January 2025.

Appendix T8. The proximate compositions of eggs samples collected throughout the duration of the project in g per egg based on the average egg weights in Appendix T15.

Month	Sample	Type	Ash (g/ egg)	Protein (g/ egg)	Water (g/ egg)	Lipid (g/ egg)
January	Hrísey	egg	0.4	4.4	27.3	4.4
	Flóahreppur 2	egg	0.6	6.5	43.5	5.2
	Flóahreppur 3	egg	0.6	6.9	45.3	5.8
	Vatnsleysuströnd	egg	0.6	7.6	49.7	6.7
	Vallá*	egg	0.6	6.6	42.6	5.7
	Akureyri*	egg	0.5	6.6	43.3	5.6
	Mosfellsbær*	egg	0.6	7.4	42.8	7.0
	Hranastaður*	egg	0.4	5.4	34.2	3.8
April	Akureyri	egg	0.7	7.3	49.9	6.3
	Hrísey	egg	0.5	5.0	30.0	4.3
	Flóahreppur 3	egg	0.6	6.7	43.7	5.2
	Vatnsleysuströnd	egg	0.7	6.6	43.1	5.9
	Vallá	egg	0.6	6.1	38.7	4.7
August	Hranastaður	egg	0.4	5.7	36.6	3.9
	Akureyri	egg	0.6	6.9	47.6	5.8
	Garður	egg	0.5	5.6	31.7	5.5
	Grafarvogur	egg	0.5	6.1	37.9	5.7
	Hrísey	egg	0.5	5.2	30.8	5.1
	Flóahreppur 3	egg	0.5	6.5	40.7	5.7
	Vatnsleysuströnd	egg	0.4	5.3	33.5	3.8
	Vallá	egg	0.6	6.4	44.6	5.4
November	Flóahreppur	egg	0.5	6.2	40.4	5.6
	Vatnsleysuströnd	egg	0.5	6.4	40.2	5.6
	Denmark	egg	0.6	6.8	42.2	5.8
	Vallá	egg	0.6	7.1	44.8	5.6
	Hrísey	egg	0.5	5.2	31.9	3.7
	Hranastaður	egg	0.6	7.3	47.0	6.0

*Collected in January 2025.

Appendix T9. The fatty acid composition of egg and feed samples analysed during 2024 and 2025. All concentrations are presented as g kg^{-1} (equivalent to mg g^{-1}).

Month	Sample name	Type	C14:0	C16:0	C16:1n7	C17:0	C17:1	C18:0	C18:1 (n9+n7)	C18:2n6	C18:3n3	C20:0	C20:1 (n11+n9)	C20:2	C20:3n6	C20:4n6
January	Akureyri	egg	0.3	25.5	2.5	0.0	0.0	9.5	41.7	11.5	0.4	0.0	0.2	0.0	0.1	1.2
January	Flóahreppur 2	egg	0.1	18.8	1.1	0.1	0.0	6.7	33.3	19.4	1.2	0.0	0.2	0.1	0.1	1.4
January	Hranastadður	egg	0.2	22.3	2.1	0.0	0.1	7.7	37.2	11.4	0.3	0.0	0.2	0.0	0.0	1.2
January	Hrísey	egg	0.2	25.6	1.8	0.2	0.0	10.7	49.6	18.4	0.5	0.0	0.3	0.1	0.1	1.9
January	Mosfellsbær	egg	0.3	30.5	2.4	0.0	0.0	10.1	49.7	18.6	0.5	0.0	0.2	0.2	0.2	2.3
January	Vallá	egg	0.2	25.7	2.1	0.0	0.0	9.2	41.8	15.9	0.4	0.0	0.2	0.1	0.1	1.8
January	Vatnsleysuströnd	egg	0.2	22.5	1.5	0.2	0.0	9.8	41.4	16.7	0.4	0.0	0.2	0.1	0.1	1.7
January	Flóahreppur 3	egg	0.1	19.2	1.2	0.2	0.0	6.9	42.1	17.0	1.1	0.0	0.2	0.1	0.1	1.4
January	Feed 50+	feed	0.1	6.6	0.0	0.0	0.0	1.0	10.7	20.2	1.4	0.1	0.2	0.0	0.0	0.0
January	Feed 19-50	feed	0.1	7.0	0.0	0.0	0.0	1.1	11.7	22.5	1.5	0.1	0.2	0.0	0.0	0.0
January	Organic 2	feed	0.0	5.4	0.0	0.0	0.0	1.6	18.3	21.5	2.6	0.2	0.3	0.0	0.0	0.0
January	Organic 3	feed	0.1	6.2	0.0	0.0	0.0	1.5	22.9	25.4	3.7	0.2	0.4	0.0	0.0	0.0
April	Akureyri	egg	0.3	23.9	2.3	0.2	0.0	8.9	42.6	11.8	0.4	0.0	0.3	0.1	0.0	1.2
April	Flóahreppur 3	egg	0.2	20.0	1.3	0.2	0.0	6.3	37.3	17.8	1.1	0.0	0.3	0.2	0.0	1.2
April	Hrísey Apr	egg	0.2	24.4	1.6	0.2	0.0	9.2	45.0	17.9	0.5	0.0	0.3	0.1	0.0	1.8
April	Vallá	egg	0.2	22.6	1.6	0.2	0.0	8.5	38.3	14.0	0.4	0.0	0.3	0.1	0.0	1.5
April	Vatnsleysuströnd	egg	0.2	25.5	1.9	0.2	0.0	9.2	42.5	17.1	0.4	0.0	0.3	0.1	0.0	1.5
April	Feed 50+	feed	0.1	7.0	0.1	0.0	0.0	1.0	5.8	8.0	0.5	0.1	0.4	0.0	0.0	0.0
April	Organic 3	feed	0.1	6.9	0.1	0.0	0.0	1.8	20.0	21.3	2.8	0.3	0.8	0.0	0.0	0.0
August	Akureyri	egg	0.2	24.2	2.2	0.2	0.0	8.9	42.7	11.2	0.3	0.0	0.2	0.0	0.0	1.3
August	Flóahreppur 2	egg	0.0	24.4	1.7	0.2	0.0	7.6	50.6	15.4	0.5	0.0	0.2	0.1	0.0	1.7
August	Garður	egg	0.7	31.1	3.0	0.2	0.0	9.5	60.5	12.5	0.7	0.0	0.2	0.0	0.0	2.0
August	Grafarvogur	egg	0.3	24.8	2.0	0.3	0.1	9.7	50.0	17.1	0.5	0.0	0.3	0.2	0.0	2.2
August	Hranastadður	egg	0.2	22.1	2.0	0.1	0.0	7.6	35.6	10.7	0.3	0.0	0.2	0.0	0.0	1.2
August	Hrísey	egg	0.3	29.3	2.6	0.2	0.1	10.6	52.3	19.7	0.6	0.0	0.3	0.2	0.0	2.3
August	Vallá	egg	0.2	22.9	1.9	0.1	0.1	8.4	39.7	14.4	0.4	0.0	0.2	0.0	0.0	1.6
August	Vatnsleysuströnd	egg	0.2	22.1	1.7	0.2	0.0	7.9	35.1	15.6	0.5	0.0	0.2	0.1	0.0	1.7
August	Feed 19-50	feed	0.1	5.9	0.1	0.0	0.0	0.9	11.7	18.7	1.3	0.1	0.2	0.0	0.0	0.0
August	Organic 2	feed	0.0	6.2	0.0	0.0	0.0	1.5	30.8	18.1	1.7	0.2	0.3	0.0	0.0	0.0
November	Denmark	egg	0.2	26.2	2.4	0.2	0.1	8.6	38.8	21.0	0.9	0.0	0.2	0.2	0.2	1.8
November	Flóahreppur	egg	0.2	25.0	1.7	0.2	0.1	7.5	49.0	16.1	0.5	0.0	0.2	0.1	0.1	1.7
November	Hranastadður	egg	0.3	24.5	2.4	0.2	0.1	9.4	42.6	11.8	0.3	0.0	0.2	0.1	0.1	1.3
November	Hrísey	egg	0.2	20.0	1.4	0.2	0.1	7.9	36.0	12.6	0.3	0.0	0.2	0.1	0.0	1.6
November	Vallá	egg	0.2	24.1	2.0	0.2	0.1	8.9	39.3	14.7	0.4	0.0	0.2	0.1	0.1	1.6
November	Vatnsleysuströnd	egg	0.2	26.1	2.0	0.2	0.1	9.1	42.5	18.6	0.4	0.0	0.2	0.1	0.1	1.8

Appendix T9 (continued). The fatty acid composition of egg and feed samples analysed during 2024 and 2025. All concentrations are presented as g kg^{-1} (equivalent to mg g^{-1}).

Month	Sample name	Type	EPA	C22:1 (n11+n9)	C22:4n6	C22:5n3	DHA	SFA	MUFA	PUFA	Unknown	DHA + EPA	Total Omega-3
January	Akureyri	egg	0.2	0.0	0.0	0.1	1.5	35.3	44.4	15.0	2.3	1.7	2.2
January	Flóahreppur 2	egg	0.0	0.2	0.1	0.1	0.9	25.8	34.7	23.4	7.5	0.9	2.2
January	Hranastadður	egg	0.1	0.0	0.0	0.1	1.6	30.3	39.6	15.1	2.1	1.8	2.2
January	Hrísey	egg	0.0	0.0	0.1	0.1	1.0	36.7	51.7	22.4	6.6	1.0	1.6
January	Mosfellsbær	egg	0.0	0.0	0.9	0.2	0.8	40.9	52.3	23.9	2.9	0.8	1.5
January	Vallá	egg	0.0	0.0	0.2	0.1	0.9	35.1	44.1	19.5	2.3	0.9	1.4
January	Vatnsleysuströnd	egg	0.0	0.0	0.1	0.1	0.9	32.7	43.1	20.2	10.7	0.9	1.4
January	Flóahreppur 3	egg	0.0	0.5	0.1	0.1	0.9	26.4	44.1	20.9	4.8	0.9	2.1
January	Feed 50+	feed	0.0	0.2	0.0	0.0	0.0	7.8	11.1	21.6	0.5	0.0	1.4
January	Feed 19-50	feed	0.0	0.3	0.0	0.0	0.0	8.3	12.2	24.0	0.5	0.0	1.5
January	Organic 2	feed	0.0	0.3	0.0	0.0	0.0	7.3	18.9	24.1	1.6	0.0	2.6
January	Organic 3	feed	0.0	0.3	0.0	0.0	0.0	8.0	23.5	29.0	1.4	0.0	3.7
April	Akureyri	egg	0.0	0.0	0.1	0.1	1.4	33.2	45.2	13.6	4.0	1.4	1.8
April	Flóahreppur 3	egg	0.0	0.0	0.1	0.1	0.9	26.7	38.8	19.8	3.8	0.9	2.0
April	Hrísey Apr	egg	0.0	0.0	0.2	0.1	0.9	34.0	46.8	19.3	4.8	0.9	1.5
April	Vallá	egg	0.0	0.0	0.2	0.0	0.7	31.4	40.2	15.1	4.3	0.7	1.1
April	Vatnsleysuströnd	egg	0.0	0.0	0.2	0.1	0.8	35.0	44.8	18.8	3.9	0.8	1.3
April	Feed 50+	feed	0.0	0.0	0.1	0.0	0.1	8.2	6.2	8.6	9.9	0.1	0.6
April	Organic 3	feed	0.0	0.0	0.0	0.0	0.3	9.0	20.9	24.2	10.9	0.3	3.1
August	Akureyri	egg	0.0	0.0	0.0	0.0	1.5	33.4	45.1	12.9	2.5	1.5	1.8
August	Flóahreppur 2	egg	0.0	0.0	0.2	0.1	1.0	32.2	52.6	19.1	2.1	1.0	1.6
August	Garður	egg	0.0	0.0	0.2	0.3	1.9	41.5	63.7	15.6	5.1	1.9	2.9
August	Grafarvogur	egg	0.0	0.0	0.4	0.2	1.3	35.0	52.4	19.6	5.0	1.3	2.0
August	Hranastadður	egg	0.0	0.0	0.0	0.0	1.7	30.1	37.8	12.7	2.4	1.7	2.0
August	Hrísey	egg	0.0	0.0	0.3	0.2	1.2	40.4	55.3	22.1	4.2	1.2	1.9
August	Vallá	egg	0.0	0.0	0.2	0.1	0.8	31.7	41.9	15.9	3.5	0.8	1.3
August	Vatnsleysuströnd	egg	0.0	0.0	0.3	0.1	0.9	30.4	37.0	19.2	1.4	0.9	1.5
August	Feed 19-50	feed	0.0	0.2	0.0	0.1	0.1	7.0	12.2	20.1	0.6	0.1	1.5
August	Organic 2	feed	0.0	0.1	0.0	0.0	0.1	7.9	31.2	19.9	0.9	0.1	1.8
November	Denmark	egg	0.0	0.0	0.2	0.1	0.9	35.2	41.4	25.2	2.2	0.9	1.9
November	Flóahreppur	egg	0.0	0.0	0.2	0.1	1.0	32.9	51.0	19.7	1.4	1.0	1.6
November	Hranastadður	egg	0.0	0.0	0.0	0.1	1.6	34.3	45.3	15.3	2.1	1.6	1.9
November	Hrísey	egg	0.0	0.0	0.2	0.1	0.8	28.2	37.7	15.7	3.5	0.8	1.2
November	Vallá	egg	0.0	0.0	0.2	0.1	0.8	33.4	41.6	18.1	1.9	0.8	1.3
November	Vatnsleysuströnd	egg	0.0	0.0	0.2	0.1	0.9	35.6	44.8	22.3	1.4	0.9	1.4

Appendix T10. The fatty acid composition of egg samples analysed during 2024 and 2025. All concentrations are presented as mg per whole egg based on the average egg weights in Appendix T15.

Month	Sample name	C14:0	C16:0	C16:1n7	C17:0	C17:1	C18:0	C18:1 (n9+n7)	C18:2n6	C18:3n3	C20:1 (n11+n9)	C20:2	C20:3n6	C20:4n6
January	Hranastadður	9	984	93	0	4	341	1639	505	14	10	0	0	54
January	Akureyri	16	1460	141	0	0	545	2384	659	23	13	0	7	70
January	Hrísey	7	949	67	7	0	396	1842	683	19	10	5	5	71
January	Flóahreppur 3	7	1070	62	8	0	384	1898	1107	67	9	8	8	82
January	Flóahreppur 2	7	1150	74	9	0	415	2521	1021	65	14	9	8	85
January	Vatnsleysuströnd	11	1424	92	11	0	620	2618	1056	27	16	9	8	108
January	Mosfellsbær	20	1769	139	0	0	586	2888	1081	26	14	10	9	135
January	Vallá	13	1440	119	0	0	513	2342	892	25	14	7	8	99
April	Akureyri	19	1570	151	13	0	587	2800	776	25	19	6	0	76
April	Hrísey	9	999	65	9	0	379	1847	732	22	13	4	0	73
April	Flóahreppur 3	10	1165	78	10	0	368	2170	1036	62	16	10	0	67
April	Vatnsleysuströnd	12	1478	112	12	0	532	2466	994	24	18	6	0	89
April	Vallá	9	1165	85	9	0	437	1977	723	19	14	5	0	75
August	Hranastadður	11	1051	96	6	0	360	1691	506	16	9	0	0	55
August	Akureyri	15	1498	135	10	0	551	2645	692	20	13	0	0	82
August	Garður	29	1361	129	10	0	415	2646	548	32	10	0	0	86
August	Grafarvogur	15	1253	101	13	6	489	2529	865	27	13	9	0	109
August	Hrísey	11	1225	111	9	4	443	2185	822	25	12	7	0	96
August	Vatnsleysuströnd	8	957	75	7	0	343	1518	677	20	10	6	0	72
August	Flóahreppur 2	0	1318	93	9	0	411	2728	830	29	13	6	0	94
August	Vallá	11	1336	113	8	4	491	2314	841	23	13	0	0	92
November	Denmark	13	1467	131	9	4	478	2167	1175	50	11	10	9	100
November	Hranastadður	16	1508	150	10	5	576	2618	728	19	14	5	7	79
November	Hrísey	8	865	59	8	4	341	1560	546	14	8	5	0	68
November	Flóahreppur 3	10	1328	90	9	4	399	2609	855	28	11	6	7	90
November	Vatnsleysuströnd	11	1399	105	9	4	486	2278	997	23	12	8	7	96
November	Vallá	13	1415	117	9	4	521	2308	864	24	12	6	7	96

Month	Sample name	EPA	C22:4n 6	C22:5n3	DHA	SFA	MUFA	PUFA	Unknown	DHA + EPA	Total Omega-3
January	Hranastadður	5	0	5	73	1335	1746	664	92	78	97
January	Akureyri	9	0	6	87	2021	2537	861	130	96	124
January	Hrísey	0	4	4	38	1361	1919	830	246	38	61
January	Flóahreppur 3	0	4	4	54	1470	1979	1333	428	54	125
January	Flóahreppur 2	0	5	5	55	1581	2642	1253	286	55	125
January	Vatnsleysuströnd	0	7	5	58	2066	2726	1279	674	58	90
January	Mosfellsbær	0	50	13	49	2376	3041	1387	168	49	88
January	Vallá	0	11	5	48	1967	2475	1094	130	48	78
April	Akureyri	0	6	6	95	2182	2971	896	265	95	120
April	Hrísey	0	9	4	39	1395	1920	792	198	39	60
April	Flóahreppur 3	0	5	5	52	1554	2258	1150	223	52	114
April	Vatnsleysuströnd	0	12	6	47	2028	2596	1088	225	47	77
April	Vallá	0	9	0	38	1620	2075	779	221	38	56
August	Hranastadður	0	0	0	79	1429	1796	601	116	79	95
August	Akureyri	0	0	0	90	2074	2794	803	158	90	110
August	Garður	0	7	11	85	1815	2785	683	222	85	128
August	Grafarvogur	0	19	9	65	1770	2650	993	254	65	101
August	Hrísey	0	12	7	49	1688	2312	923	177	49	81
August	Vatnsleysuströnd	0	11	4	40	1315	1603	830	62	40	64
August	Flóahreppur 2	0	10	4	54	1738	2833	1027	115	54	87
August	Vallá	0	11	4	48	1847	2443	927	205	48	75
November	Denmark	0	10	5	48	1970	2314	1407	123	48	103
November	Hranastadður	0	0	5	95	2109	2788	940	129	95	120
November	Hrísey	0	8	4	33	1222	1631	678	149	33	52
November	Flóahreppur 3	0	8	3	51	1750	2715	1049	73	51	83
November	Vatnsleysuströnd	0	9	4	48	1908	2399	1193	75	48	76
November	Vallá	0	11	4	49	1961	2441	1061	114	49	77

Appendix T11. The concentrations of trace elements, minerals and toxic elements in egg and feed samples analysed during 2024 and 2025. All concentrations are presented in mg kg^{-1} wet weight.

Sample name	Type	Month	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se
Organic 2	feed	January	2.94	12.0	202	610	0.449	6.72	31.2	124	0.329	0.710
Organic 3	feed	January	2.68	4.51	133	703	0.271	3.27	16.3	108	0.236	0.322
Feed 19-50	feed	January	0.418	0.653	147	136	0.785	0.747	19.8	87.9	0.066	0.292
Feed 50+	feed	January	0.553	0.879	164	218	0.830	0.903	20.9	91.4	0.085	0.377
Flóahreppur 3	egg	January	<0.07	<0.05	0.466	19.1	<0.01	<0.05	0.706	15.5	<0.02	0.272
Vatnsleysuströnd	egg	January	<0.07	<0.05	0.425	14.2	<0.01	<0.05	0.516	11.9	<0.02	<0.2
Mosfellsær	egg	January	<0.07	<0.05	0.514	20.9	<0.01	<0.05	0.594	15.1	<0.02	0.462
Hranastaður	egg	January	<0.07	<0.05	0.353	17.0	<0.01	<0.05	0.534	11.9	0.020	0.324
Vallá	egg	January	<0.07	<0.05	0.570	20.8	<0.01	<0.05	0.655	14.5	<0.02	0.238
Akureyri	egg	January	<0.07	<0.05	0.467	19.3	<0.01	<0.05	0.665	14.4	0.033	0.304
Hrísey	egg	January	<0.07	<0.05	0.399	20.4	<0.01	<0.05	0.604	16.0	<0.02	0.362
Flóahreppur 2	egg	January	<0.07	<0.05	0.520	20.5	<0.01	<0.05	0.725	14.5	<0.02	0.338
Organic 3	feed	April	2.03	3.31	142	493	0.228	2.97	15.2	104	0.194	0.336
Feed 50+	feed	April	0.185	0.511	102	101	0.104	0.756	18.8	69.7	0.062	0.300
Vatnsleysuströnd	egg	April	<0.07	<0.05	0.495	18.5	<0.01	<0.05	0.666	18.9	<0.02	0.204
Vallá	egg	April	<0.07	<0.05	0.592	20.3	<0.01	<0.05	0.682	19.3	<0.02	0.205
Flóahreppur 3	egg	April	<0.07	<0.05	0.258	13.1	<0.01	<0.05	0.466	9.4	<0.02	0.225
Akureyri	egg	April	<0.07	<0.05	0.462	17.8	<0.01	<0.05	0.600	16.9	0.027	0.259
Hrísey	egg	April	<0.07	<0.05	0.406	16.3	<0.01	<0.05	0.548	14.1	<0.02	0.259
Organic 2	feed	August	2.59	4.72	161	542	0.434	2.12	24.5	175	0.428	0.609
Feed 19-50	feed	August	1.917	5.86	124	709	0.746	8.11	16.3	118	0.709	0.436
Flóahreppur 2	egg	August	<0.07	<0.05	0.406	19.3	<0.01	<0.05	0.632	19.7	<0.02	0.358
Akureyri	egg	August	<0.07	<0.05	0.354	16.6	<0.01	<0.05	0.587	15.9	<0.02	0.255
Grafarvogur	egg	August	<0.07	<0.05	0.568	31.3	<0.01	<0.05	1.002	23.5	<0.02	0.406
Garður	egg	August	<0.07	<0.05	0.405	24.6	<0.01	<0.05	0.885	22.4	<0.02	0.235
Hranastaður	egg	August	<0.07	<0.05	0.356	18.2	<0.01	<0.05	0.577	15.3	0.019	0.302
Hrísey	egg	August	<0.07	<0.05	0.382	20.7	<0.01	<0.05	0.661	16.5	<0.02	0.248
Vatnsleysuströnd	egg	August	<0.07	<0.05	0.366	17.7	<0.01	<0.05	0.556	15.5	<0.02	0.249
Vallá	egg	August	<0.07	<0.05	0.531	18.0	<0.01	<0.05	0.549	13.5	<0.02	<0.2
Flóahreppur	egg	November	<0.07	<0.05	0.427	20.8	<0.01	<0.05	0.630	19.0	<0.02	0.345
Hranastaður	egg	November	<0.07	<0.05	0.370	15.6	<0.01	<0.05	0.545	16.4	0.029	0.270
Hrísey	egg	November	<0.07	<0.05	0.368	20.7	<0.01	<0.05	0.646	22.7	<0.02	0.321
Denmark	egg	November	<0.07	<0.05	0.453	18.4	<0.01	<0.05	0.569	17.5	<0.02	0.200
Vatnsleysuströnd	egg	November	<0.07	<0.05	0.554	18.8	<0.01	<0.05	0.636	20.4	<0.02	0.266
Vallá	egg	November	<0.07	<0.05	0.475	18.3	<0.01	<0.05	0.606	17.3	<0.02	0.229

Appendix T11 (continued). The concentrations of trace elements, minerals and toxic elements in egg and feed samples analysed during 2024 and 2025. All concentrations are presented in mg kg^{-1} wet weight.

Sample name	Type	Month	Mo	Cd	Sn	Hg	Pb	Na	Mg	P	K	Ca
Organic 2	feed	January	2.38	0.226	0.073	<0.02	0.506	1844	3831	4833	6592	75143
Organic 3	feed	January	1.52	0.170	0.055	<0.02	0.326	1451	2143	5587	7174	36331
Feed 19-50	feed	January	1.12	0.087	0.010	<0.02	0.213	1091	1571	4113	6437	27022
Feed 50+	feed	January	1.11	0.171	0.019	<0.02	0.507	1044	1691	4273	6431	31375
Flóahreppur 3	egg	January	0.133	<0.01	<0.002	<0.02	<0.01	1223	121	2248	1200	567
Vatnsleysuströnd	egg	January	0.082	<0.01	<0.002	<0.02	<0.01	1577	143	2136	1364	554
Mosfellsær	egg	January	0.060	<0.01	<0.002	<0.02	<0.01	1277	107	2197	1343	566
Hranastaður	egg	January	0.056	<0.01	<0.002	0.030	<0.01	1501	144	1797	1239	494
Vallá	egg	January	0.054	<0.01	0.003	<0.02	<0.01	1368	130	2037	1217	558
Akureyri	egg	January	0.046	<0.01	0.002	0.026	<0.01	1407	131	2165	1294	608
Hrísey	egg	January	0.040	<0.01	<0.002	<0.02	<0.01	1173	117	2228	1238	517
Flóahreppur 2	egg	January	0.038	<0.01	<0.002	<0.02	<0.01	1248	145	2198	1143	525
Organic 3	feed	April	1.26	0.163	0.048	<0.02	0.282	1528	2047	5317	6435	37315
Feed 50+	feed	April	0.692	0.051	0.013	<0.02	0.120	1397	1307	3305	5285	36278
Vatnsleysuströnd	egg	April	0.059	<0.01	<0.002	<0.02	<0.01	1160	98	1803	1049	505
Vallá	egg	April	0.058	<0.01	<0.002	<0.02	<0.01	1197	113	1802	1039	510
Flóahreppur 3	egg	April	0.049	<0.01	<0.002	<0.02	<0.01	1014	89	1486	881	405
Akureyri	egg	April	0.047	<0.01	<0.002	<0.02	<0.01	1131	99	1721	968	453
Hrísey	egg	April	0.040	<0.01	<0.002	<0.02	<0.01	1054	96	1907	973	517
Organic 2	feed	August	1.41	0.188	0.031	<0.02	0.438	1252	2696	6467	6689	21770
Feed 19-50	feed	August	0.711	0.049	0.019	<0.02	0.147	1505	2535	4063	6054	26648
Flóahreppur 2	egg	August	0.122	<0.01	<0.002	<0.02	<0.01	1271	123	2149	1133	545
Akureyri	egg	August	0.096	<0.01	<0.002	<0.02	<0.01	1170	94	1587	1230	410
Grafarvogur	egg	August	0.063	<0.01	<0.002	<0.02	<0.01	1189	112	1889	1337	495
Garður	egg	August	0.054	<0.01	<0.002	<0.02	0.070	1195	104	2122	1268	594
Hranastaður	egg	August	0.049	<0.01	<0.002	<0.02	<0.01	1333	121	1608	1234	415
Hrísey	egg	August	0.049	<0.01	<0.002	<0.02	<0.01	1178	106	2086	1302	566
Vatnsleysuströnd	egg	August	0.035	<0.01	<0.002	<0.02	0.013	1347	142	1710	1125	432
Vallá	egg	August	0.034	<0.01	0.003	<0.02	<0.01	1119	106	1659	1125	446
Flóahreppur	egg	November	0.127	<0.01	0.002	<0.02	<0.01	1204	121	2106	1173	527
Hranastaður	egg	November	0.067	<0.01	<0.002	0.022	<0.01	1312	131	1992	1151	506
Hrísey	egg	November	0.062	<0.01	<0.002	<0.02	<0.01	1184	120	2357	1158	597
Denmark	egg	November	0.054	<0.01	0.002	<0.02	<0.01	1218	116	2055	1142	519
Vatnsleysuströnd	egg	November	0.047	<0.01	<0.002	<0.02	0.011	1334	124	2271	1205	581
Vallá	egg	November	0.043	<0.01	<0.002	<0.02	<0.01	1282	129	2009	1122	528

Appendix T12. The concentrations of trace elements, minerals and toxic elements in egg and feed samples analysed during 2024 and 2025. All concentrations are presented in mg per egg based on egg weights in Appendix T15.

Sample name	Month	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se
Flóahreppur 3	January	<LOQ	<LOQ	0.03	1.15	<LOQ	<LOQ	0.04	0.93	<LOQ	0.02
Vatnsleysuströnd	January	<LOQ	<LOQ	0.03	0.90	<LOQ	<LOQ	0.03	0.75	<LOQ	<LOQ
Mosfellsær	January	<LOQ	<LOQ	0.03	1.22	<LOQ	<LOQ	0.03	0.88	<LOQ	0.03
Hranastaður	January	<LOQ	<LOQ	0.02	0.75	<LOQ	<LOQ	0.02	0.52	0.001	0.01
Vallá	January	<LOQ	<LOQ	0.03	1.17	<LOQ	<LOQ	0.04	0.82	<LOQ	0.01
Akureyri	January	<LOQ	<LOQ	0.03	1.10	<LOQ	<LOQ	0.04	0.82	0.002	0.02
Hrísey	January	<LOQ	<LOQ	0.01	0.76	<LOQ	<LOQ	0.02	0.59	<LOQ	0.01
Flóahreppur 2	January	<LOQ	<LOQ	0.03	1.17	<LOQ	<LOQ	0.04	0.83	<LOQ	0.02
Vatnsleysuströnd	April	<LOQ	<LOQ	0.03	1.07	<LOQ	<LOQ	0.04	1.10	<LOQ	0.01
Vallá	April	<LOQ	<LOQ	0.03	1.05	<LOQ	<LOQ	0.04	1.00	<LOQ	0.01
Flóahreppur 3	April	<LOQ	<LOQ	0.02	0.76	<LOQ	<LOQ	0.03	0.55	<LOQ	0.01
Akureyri	April	<LOQ	<LOQ	0.03	1.17	<LOQ	<LOQ	0.04	1.11	0.002	0.02
Hrísey	April	<LOQ	<LOQ	0.02	0.67	<LOQ	<LOQ	0.02	0.58	<LOQ	0.01
Flóahreppur 2	August	<LOQ	<LOQ	0.02	1.04	<LOQ	<LOQ	0.03	1.06	<LOQ	0.02
Akureyri	August	<LOQ	<LOQ	0.02	1.03	<LOQ	<LOQ	0.04	0.98	<LOQ	0.02
Grafarvogur	August	<LOQ	<LOQ	0.03	1.58	<LOQ	<LOQ	0.05	1.19	<LOQ	0.02
Garður	August	<LOQ	<LOQ	0.02	1.08	<LOQ	<LOQ	0.04	0.98	<LOQ	0.01
Hranastaður	August	<LOQ	<LOQ	0.02	0.86	<LOQ	<LOQ	0.03	0.73	0.001	0.01
Hrísey	August	<LOQ	<LOQ	0.02	0.86	<LOQ	<LOQ	0.03	0.69	<LOQ	0.01
Vatnsleysuströnd	August	<LOQ	<LOQ	0.02	0.77	<LOQ	<LOQ	0.02	0.67	<LOQ	0.01
Vallá	August	<LOQ	<LOQ	0.03	1.05	<LOQ	<LOQ	0.03	0.79	<LOQ	<LOQ
Flóahreppur	November	<LOQ	<LOQ	0.02	1.11	<LOQ	<LOQ	0.03	1.01	<LOQ	0.02
Hranastaður	November	<LOQ	<LOQ	0.02	0.96	<LOQ	<LOQ	0.03	1.01	0.002	0.02
Hrísey	November	<LOQ	<LOQ	0.02	0.89	<LOQ	<LOQ	0.03	0.98	<LOQ	0.01
Denmark	November	<LOQ	<LOQ	0.03	1.03	<LOQ	<LOQ	0.03	0.98	<LOQ	0.01
Vatnsleysuströnd	November	<LOQ	<LOQ	0.03	1.01	<LOQ	<LOQ	0.03	1.09	<LOQ	0.01
Vallá	November	<LOQ	<LOQ	0.03	1.08	<LOQ	<LOQ	0.04	1.01	<LOQ	0.01

Sample name	Month	Mo	Cd	Sn	Hg	Pb	Na	Mg	P	K	Ca
Flóahreppur 3	January	0.01	<LOQ	<LOQ	<LOQ	<LOQ	73.3	7.25	134.7	71.9	34.0
Vatnsleysuströnd	January	0.01	<LOQ	<LOQ	<LOQ	<LOQ	99.7	9.03	135.0	86.2	35.0
Mosfellsær	January	0.00	<LOQ	<LOQ	<LOQ	<LOQ	74.2	6.21	127.7	78.0	32.9
Hranastaður	January	0.00	<LOQ	<LOQ	0.001	<LOQ	66.2	6.36	79.3	54.6	21.8
Vallá	January	0.00	<LOQ	0.0002	<LOQ	<LOQ	76.7	7.28	114.3	68.3	31.3
Akureyri	January	0.00	<LOQ	0.0001	0.001	<LOQ	80.5	7.47	123.8	74.0	34.8
Hrísey	January	0.00	<LOQ	<LOQ	<LOQ	<LOQ	43.5	4.33	82.6	45.9	19.2
Flóahreppur 2	January	0.00	<LOQ	<LOQ	<LOQ	<LOQ	71.2	8.27	125.3	65.2	30.0
Vatnsleysuströnd	April	0.00	<LOQ	<LOQ	<LOQ	<LOQ	67.3	5.70	104.5	60.8	29.3
Vallá	April	0.00	<LOQ	<LOQ	<LOQ	<LOQ	61.8	5.85	93.0	53.7	26.3
Flóahreppur 3	April	0.00	<LOQ	<LOQ	<LOQ	<LOQ	59.0	5.19	86.4	51.2	23.6
Akureyri	April	0.00	<LOQ	<LOQ	<LOQ	<LOQ	74.4	6.48	113.1	63.6	29.8
Hrísey	April	0.00	<LOQ	<LOQ	<LOQ	<LOQ	43.3	3.92	78.2	39.9	21.2
Flóahreppur 2	August	0.01	<LOQ	<LOQ	<LOQ	<LOQ	68.5	6.65	115.8	61.1	29.4
Akureyri	August	0.01	<LOQ	<LOQ	<LOQ	<LOQ	72.5	5.80	98.4	76.3	25.4
Grafarvogur	August	0.00	<LOQ	<LOQ	<LOQ	<LOQ	60.2	5.66	95.6	67.6	25.0
Garður	August	0.00	<LOQ	<LOQ	<LOQ	0.003	52.2	4.53	92.7	55.4	25.9
Hranastaður	August	0.00	<LOQ	<LOQ	<LOQ	<LOQ	63.3	5.73	76.4	58.6	19.7
Hrísey	August	0.00	<LOQ	<LOQ	<LOQ	<LOQ	49.2	4.42	87.2	54.4	23.7
Vatnsleysuströnd	August	0.00	<LOQ	<LOQ	<LOQ	0.001	58.5	6.17	74.2	48.8	18.7
Vallá	August	0.00	<LOQ	0.0002	<LOQ	<LOQ	65.2	6.16	96.7	65.6	26.0
Flóahreppur	November	0.01	<LOQ	0.0001	<LOQ	<LOQ	64.1	6.43	112.1	62.4	28.1
Hranastaður	November	0.00	<LOQ	<LOQ	0.001	<LOQ	80.7	8.09	122.5	70.8	31.1
Hrísey	November	0.00	<LOQ	<LOQ	<LOQ	<LOQ	51.3	5.18	102.0	50.1	25.9
Denmark	November	0.00	<LOQ	0.0001	<LOQ	<LOQ	68.1	6.46	114.9	63.9	29.0
Vatnsleysuströnd	November	0.00	<LOQ	<LOQ	<LOQ	0.001	71.5	6.67	121.8	64.6	31.2
Vallá	November	0.00	<LOQ	<LOQ	<LOQ	<LOQ	75.2	7.58	117.9	65.9	31.0

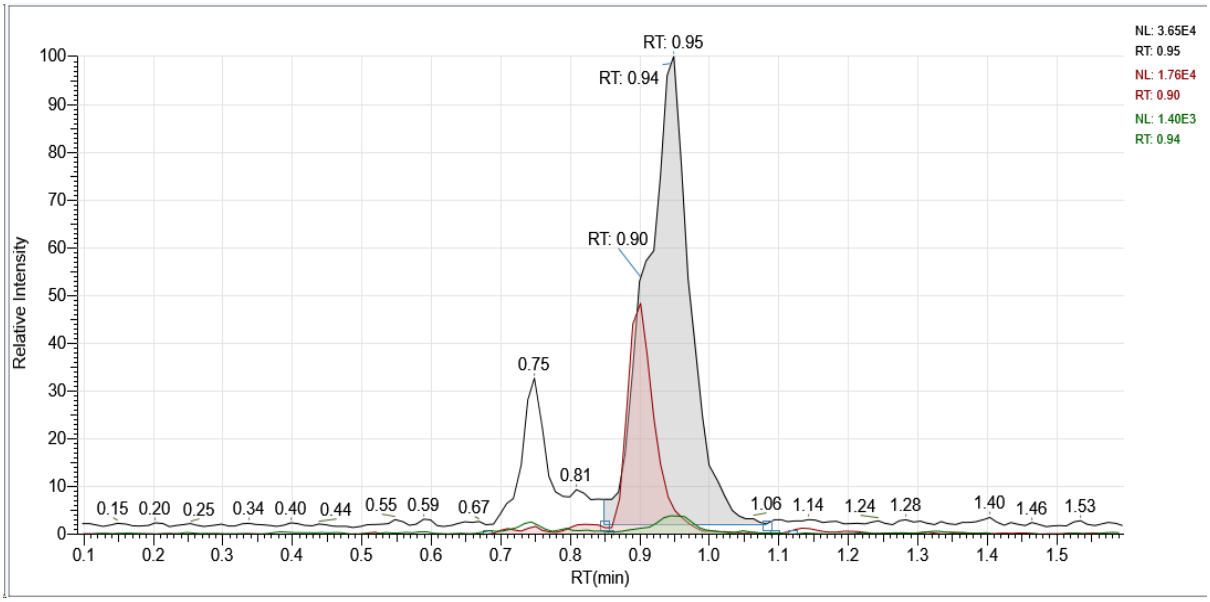
Appendix T13. The arsenic speciation in 4 samples of hen feed collected in January. The arsenobetaine detected is indicative of the fishmeal used in the regular feed but removed from the organic feed over concerns from PFAS contamination.

Sample	iAs (mg kg^{-1})	Arsenobetaine (mg kg^{-1})	Extraction efficiency (%)	Column recovery (%)
Organic 2	0.100 ± 0.007	<LOQ	38 ± 3	94 ± 11
Organic 3	0.081 ± 0.004	<LOQ	23 ± 1	107 ± 6
Feed 19-50	0.024 ± 0.003	0.024 ± 0.004	49 ± 2	104 ± 4
Feed 50+	0.028 ± 0.003	0.021 ± 0.001	45 ± 5	105 ± 10

LOQ = 0.018 mg kg^{-1}

Extraction: Approximately 200 mg of homogenised feed material was added to quartz digestion tubes before the addition of 10 mL of a 2% (v/v) nitric acid and 3% (v/v) hydrogen peroxide solution. The digestion tubes were transferred to an Ultrawave microwave digestion system (Milestone, Italy) for microwave-assisted extraction at 90°C for 40 minutes. Once cooled, sample mixtures were transferred to 50 mL polypropylene falcon tubes and centrifuged at 4000 rpm for 15 min. A 1 mL aliquot of the supernatant was subjected to further centrifugation at 15000 rpm (15 min) before direct analysis with HPLC-ICP-MS. To calculate the column recovery, 1 mL of the original supernatant was diluted 10 mL with ultrapure water and analysed for total arsenic as previously described.

Analysis: Extracts were analysed using an Agilent Infinity 1200 LC coupled to an Agilent 7900 ICP-MS. Analytes were separated using a strong anion exchange column (Hamilton PRP-X100, 5 µm, 150 x 4.6 mm) and isocratic elution with 60 mM ammonium carbonate mobile phase (1 mL min^{-1}). The ICP-MS was run in He gas mode to remove any isobaric interferences, and the sample injection volume was 40 µL



Appendix F3. The extracted ion chromatograph showing the large interferent peak co-eluting with PFBA on mass transition 213->169 m/z (black). The isotopically labelled PFBA internal standard (red) shows the actual retention time of PFBA. The mass transition 213-> 125.1 m/z which is a common fatty acid is fragment is also shown (green) suggesting the interferent is of this class of compound.

Appendix T14. The concentrations of PFAS in samples of egg and feed collected throughout the project. All concentrations are shown as μg kg^{-1} wet weight. Compounds not detected in any samples were omitted from the table.

Month	Sample name	Type	PFBA	PFOA	PFNA	PFDA	PFUnDA	PFDoA	PFTrDA	PFTeDA	PFHxS	PFOS	PFDS	PFDoS	6:2FTS
January	Organic 2	feed	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.10
January	Organic 3	feed	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.10
January	Feed 19-50	feed	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.13
January	Feed 50+	feed	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.10
January	Flóahreppur 3	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
January	Vatnsleysuströnd	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
January	Mosfellsbær	egg	0.11	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
January	Hranastaður	egg	<0.1	<0.03	<0.03	<0.03	0.05	<0.05	<0.05	<0.05	<0.05	0.18	<0.05	<0.05	<0.1
January	Vallá	egg	0.12	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
January	Akureyri	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
January	Hrísey	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
January	Flóahreppur 2	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
February	Njarðvik	egg	<0.1	<0.03	0.04	0.09	<0.05	0.06	<0.05	0.05	<0.05	0.23	<0.05	<0.05	<0.1
April	Organic 3	feed	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
April	Feed 50+	feed	<0.1	<0.03	<0.03	<0.03	<0.05	0.10	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
April	Vatnsleysuströnd	egg	<0.1	<0.03	<0.03	0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
April	Vallá	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
April	Flóahreppur 3	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
April	Akureyri	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.1
April	Hrísey	egg	<0.1	<0.03	<0.03	0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.1
August	Organic 2	feed	<0.1	<0.03	<0.03	<0.03	<0.05	0.10	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
August	Feed 19-50	feed	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
August	Flóahreppur 2	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
August	Akureyri	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.1
August	Grafarvogur	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
August	Garður	egg	0.15	0.03	0.10	0.09	0.12	0.23	0.17	0.27	0.07	1.47	0.20	0.05	<0.1
August	Hranastaður	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.09	<0.05	<0.05	<0.1
August	Hrísey	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
August	Vatnsleysuströnd	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
August	Vallá	egg	0.10	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
November	Flóahreppur	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
November	Hranastaður	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
November	Hrísey	egg	<0.1	<0.03	0.03	0.03	0.05	<0.05	0.06	<0.05	<0.05	0.09	<0.05	<0.05	<0.1
November	Denmark	egg	<0.1	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
November	Vatnsleysuströnd	egg	0.12	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
November	Vallá	egg	0.12	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
Multiple	Akureyri 2016	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.1
Multiple	Akureyri 2020	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.1
Multiple	Akureyri 2022	egg	NQ	<0.03	<0.03	<0.03	0.06	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.1
Multiple	Hrísey 2020	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
Multiple	Hrísey 2022	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.1
Multiple	Vatnsleysuströnd 2016	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.1
Multiple	Vatnsleysuströnd 2020	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.1
Multiple	Vatnsleysuströnd 2022	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	<0.05	<0.1
Multiple	Vallá 2016	egg	NQ	<0.03	0.03	0.03	0.09	<0.05	<0.05	<0.05	0.05	0.09	<0.05	<0.05	<0.1
Multiple	Vallá 2020	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
Multiple	Vallá 2022	egg	NQ	<0.03	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1

Appendix T15. The fluctuation in Icelandic egg weight (yolk and white, no shell) for different producers.

Producer location	January	April	August	November
Hrísey	37 ± 4.1	41 ± 2.3	42 ± 3.0	43 ± 4.1
Vallá	56 ± 1.4*	52 ± 2.6	58 ± 3.8	59 ± 2.5
Vatnsleysustönd	63 ± 6.2	58 ± 3.0	43.4 ± 1.6	54 ± 3.4
Flóahreppur (organic)	57 ± 3.1 (NB2) 60 ± 3.4 (NB3)	58 ± 2.9 (NB3)	54 ± 2.6 (NB2)	53 ± 2.9 (NB2)
Akureyri	57 ± 1.9*	66 ± 4.7	62 ± 2.6	-
Hranastaður	44 ± 4.4*	-	48 ± 3.9	62 ± 4.8
Denmark	-	-	-	56 ± 4.1
Independent Farm (Grafarvogur)	-	-	51 ± 3.5	-
Independent Farm (Garður)	-	-	44 ± 4.3	-
Mosfellsbær	58 ± 3*	-	-	-

*January 2025