



Public perceptions of per- and polyfluoroalkyl substances (PFAS): Psycho-demographic characteristics differentiating PFAS knowledge and concern

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ABSTRACT

Due to their persistence and toxicity, per- and polyfluoroalkyl substances (PFAS) have become an issue of global concern. The public's perception is valuable in consultations about possible remediation or mitigation against the use of PFAS. In this study, we investigated the source of PFAS information and factors (psycho-demographic characteristics) affecting public views. We performed an online survey with a demographically representative sample of Aotearoa New Zealand adults ($n = 935$). Results show that PFAS are known to nearly 45 % of the survey participants, yet, with misunderstandings. Amongst those aware of PFAS, the concern is high, especially for their use in products that contact skin or consumed orally. Individuals with the highest level of self-perceived PFAS knowledge (vs no knowledge) were most concerned but also the most accepting of PFAS-containing products. Males were self-perceived to be more knowledgeable and less concerned than females. Younger adults (aged 18–34) were more likely to indicate high perceived knowledge and more acceptance of consumer products containing PFAS than older adults. These findings identified crucial information gaps that will contribute to national and global regulation and policy decisions as well as inform public education campaigns, informing a more targeted education approach.

1. Introduction

Per- and polyfluoroalkyl substances (PFAS) are a class of over 9000 synthetic chemicals defined by the presence of at least one fully fluorinated methyl or methylene carbon group (OECD, 2021). The development and widespread use of PFAS was driven by their comprehensive range of useful and difficult-to-replicate physicochemical characteristics, including hydrophobicity, oleophobicity, heat resistance, low friction, and unique dielectric properties (Glüge et al., 2020). As a result, PFAS have been used extensively in industrial and consumer applications where high resilience and durability are required (Dickman and

Aga, 2022). For example, PFAS are used to create non-stick or water-resistant coatings on cookware, outdoor gear, furniture, food packaging, and carpets (Glüge et al., 2020). In the manufacturing industry, PFAS are used in processes ranging from semiconductor production to electroplating and medical implant manufacture (Glüge et al., 2020). PFAS are also a major component in Aqueous Film Forming Foams (AFFFs), used in firefighting to extinguish flammable liquids (Yao et al., 2022).

PFAS enter the environment through the production, use, and disposal of consumer goods, as well as at industrial sites where PFAS are manufactured (Sunderland et al., 2019). PFAS can also be discharged

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directly into the environment due to the uses of AFFFs at firefighting sites (Høisæter et al., 2019). This is of particular concern at military and airport sites where AFFFs are used frequently in training as well as in emergency scenarios, where the continued use of these foams contaminates groundwater and accumulates PFAS in the soil at these locations (Barzen-Hanson et al., 2017; Høisæter et al., 2019). Once released, the majority of PFAS persist in their environments near indefinitely due to the extreme stability of their carbon-fluorine bonds (Bolan et al., 2021). This stability, combined with the high mobility of these molecules, has enabled PFAS to spread across the globe in the eighty years of their large-scale manufacture (Evich et al., 2022). Attesting to their ubiquity and pervasiveness, PFAS have been detected in some of the most remote locations on Earth, from the far reaches of the Arctic (Muir et al., 2019) to depths of over 2000 m in the Labrador Sea and the Atlantic Ocean (Yamashita et al., 2008). They are also purported to be present in detectable concentrations in the blood of close to the entire human population (Fenton et al., 2021; Lenka et al., 2022).

The commonly detected PFAS in human beings and animals are problematic because these compounds are also toxic (Du et al., 2023). Although PFAS exhibit low acute toxicity, the long-term adverse effects of PFAS exposure on human health are emerging. Research has identified probable links between PFAS exposure and ulcerative colitis, thyroid disease, kidney cancer, pregnancy-induced hypertension, testicular cancer, and high cholesterol (Sunderland et al., 2019). Links have also been made between exposure in humans and low fertility, decreased breastfeeding duration and milk quality, and decreased immune function in childhood, though the mechanisms of PFAS toxicity remain largely unknown (Fenton et al., 2021).

As a subset of PFAS are now recognised as global contaminants of great concern by the OECD and many other countries, there are growing concerns to improve the management of the use and remediation of these compounds on a global scale (Bolan et al., 2021; Kang et al., 2022). The failure to reduce manufacturing and usage on a global scale in the last decade has caused a dramatic increase in production in many Asian countries because of the phase-out initiatives in North America (Stockin et al., 2021; Routti et al., 2016). Therefore, management of the use and remediation of PFAS are equally important for countries previously with or without major manufacturers to prevent unwanted migration of productions and uses of these chemicals with concerns.

While industry and policymaker perceptions are important to identify the current management landscape for PFAS, equally important is the knowledge and concern the general public has about PFAS. For example, such work has been completed on public perception and knowledge of (micro)plastics (Soares et al., 2021). However, little is known globally about the degree of public knowledge of PFAS or their concern for them. A recent survey found that over 60 % of Wisconsin residents, after (Wisconsin) lawmakers approved a new drinking water standard for PFAS, were concerned about PFAS contamination in their drinking water, with women and politically engaged individuals expressing greater concern (Wichowsky, 2023). In a nationwide survey conducted in the USA, 16 % of the respondents indicated they had heard of PFAS, with males twice as likely than females to have heard of PFAS and women four times more likely to report negative opinions of PFAS problems (Stolle and Longworth, 2020). After being presented with scientific information on PFAS, females were more worried than males about PFAS' harm (to human health, themselves as well as others) and deemed PFAS contamination a problem (Stolle and Longworth, 2020). The media plays a large role in information dissemination, Tian et al. (2022) found that social media users, across Twitter and Reddit (2017–2019) in the U.S., viewed PFAS as a significant public health concern and that PFAS discussions on social media were driven by contamination events, media coverage, and scientific publications. Research also demonstrates that Swedish consumers are willing to pay (WIP) more for garments without PFAS, even without extra information about PFAS, but WIP was even higher when specific information was provided (Holmquist et al., 2018). However, all countries have different

regulations, media exposure, consumer tolerance to risk and other factors such as history (e.g., contamination events) and consumer culture (e.g., preference for individualisation) which may affect PFAS knowledge and concern. Thus, country specific studies are welcomed to ensure accurate portrayals of consumer perspectives.

Despite the potentially significant influence of public views on the industry's use of and government's regulations and policies for PFAS, crucial knowledge gaps exist regarding the public views of PFAS. In this study, we aimed to investigate the source of PFAS information and identify the factors affecting public view on PFAS in Aotearoa New Zealand. Previous research suggests sociodemographic factors, such as age, education, and gender, can be used to predict environmental awareness (Kiesling et al., 2017), climate change concern (Driscoll, 2019), and clean energy knowledge (Karytsas and Theodoropoulou, 2014). In this study, we examined whether public PFAS knowledge and concern were differentiated by psycho-demographic characteristics, such as gender, age, ethnicity, and environmental concern of an individual.

We performed an online survey using a market research panel in Aotearoa New Zealand. Understanding the public view of PFAS in countries like Aotearoa New Zealand is important to increase global awareness and better management practices of these chemicals. Due to its unique location and economic composition, Aotearoa New Zealand has no PFAS manufacturers. The contamination events and media coverage are significantly lower than in countries like the U.S. Therefore, our findings can help identify gaps and strengthen prevention efforts (Jeffers et al., 2022). The findings will also help inform public education and awareness campaigns, specifically informing the segmentation (grouping) of the population for a more targeted social marketing approach. These educational materials can help prevent the unethical transfer of productions and uses of PFAS in countries with fewer regulations and public knowledge. Our study also contributes to a call for public health action that develops and facilitates the dissemination of public health initiatives for PFAS (Rogers et al., 2021).

2. Method

To provide a generalized overview of the psycho-demographic characteristics differentiating PFAS knowledge and concern, we performed an online survey in June 2022 using a reputable local (Aotearoa New Zealand) online market research panel. Participation in the study was entirely voluntary, and respondents were given compensation from the market research firm. To collect consumer perspectives, the use of online surveys is very common (Evans and Mathur, 2018). The use of panels is also the most common recruitment method in public polling, marketing research, and organizational research (Brüggen and Dholaria, 2010). Panel members have been found to produce better data quality than other online recruitment methods (e.g., Amazon Mechanical Turk) due to the incentives provided by market research companies (Smith et al., 2016). Informed consent was required and a total of 1000 respondents aged over 18 years old participated in the survey.

2.1. Instrument of study

A self-report questionnaire was developed with 21 questions, divided into 6 sections regarding 1) demographics; 2) environmental concerns; 3) knowledge and concern about household contaminants (not covered here); 4) knowledge and concern about PFAS. After these initial questions, scientific information was presented about PFAS, followed by another set of questions asking about 5) respondents' knowledge and 6) concern about PFAS. The survey included an overview of the aims of the study, with a consent form displayed (assuring respondents about the confidentiality of the information collected before their consent was sought to start the survey). A panel of seven academic experts assessed survey items for conceptual consistency of indicators, face validity, and content validity, after which amendments and additions were made to

the questionnaire. A pre-test ($n = 102$) was conducted to identify potential issues in the questionnaire, and no issues were identified. Information regarding the questionnaire sections is detailed next.

2.1.1. Demographic characteristics

Participants were asked to report geographical location, age, gender, ethnicity, number of children living at home, level of education, household income, and employment industry.

2.1.2. Environmental concern

Seven items were used to measure environmental concern. Five items were utilised from Kramm et al. (2022) (e.g., “There are ecological limits to growth that our industrialized world has long since reached”), and two items were created (“I feel up to date/well versed on recent scientific discussions about environmental concerns”, “For the benefit of the environment, I am willing to change my everyday behaviours”). These items were measured on a Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree).

2.1.3. General knowledge of PFAS

One item was used to indicate respondents' knowledge of PFAS, indicating one of five options on a multichoice question: “No, I have never heard about PFAS”, “Yes, I have heard about PFAS but I don't know what they are”, “Yes, I have heard about PFAS and know a little bit about them”, “Yes, I have heard about PFAS and know a lot about them”, “Yes, I have heard about PFAS as they have an impact on my health/life/job/occupation”. If respondents indicated “yes”, they were asked an open-ended question about their view on what PFAS refers to. Next, respondents were asked to indicate their level of PFAS knowledge. To indicate their level of knowledge, five items were used, adapting the items used by Kramm et al. (2022) in their microplastics study (e.g., “I have good knowledge of PFAS as an additive/ingredient in many products”, “I have a good knowledge on the distribution of PFAS”, “I have good knowledge on the impacts of PFAS on human health”), measured on a Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree).

Respondents were asked to indicate on a multichoice question what their sources of information were for their knowledge on PFAS, providing 9 multichoice options including scientific journals, social media, environmental journals, and newspapers. Based on Kramm et al. (2022), one item assessed whether respondents found the information they had previously read about PFAS easy or hard to read, offering four options on a multichoice question, “difficult”, “rather difficult”, “rather easy”, and “easy”.

Those who indicated they had heard of PFAS before were asked to indicate (via a multichoice question) which product(s) for sale in New Zealand they believed contain PFAS. The options included 14 items, such as Plastic toys, Couch/sofa, Fire extinguisher, Takeout packaging (e.g., pizza box).

2.1.4. Assessment after PFAS facts provided to participants

All respondents were provided with a short but detailed information sheet about PFAS (Appendix B). After the presentation of information, those who answered “no” to having heard of PFAS before were asked whether they found the information they had read about PFAS easy or hard to read and indicate (via multichoice question) which product(s) for sale in New Zealand they believed contain PFAS.

All respondents were asked to indicate their concern with nine items, similar to Kramm et al.'s (2022) work on microplastics. These items included items such as “PFAS that have accumulated in the body can remain in the body for a long time”, “PFAS are so ubiquitous that they are taken up by many organisms that are food sources for people”, “PFAS are everywhere in the environment, even in remote places, such as Arctic and Antarctic”. A Likert scale, ranging from 1 (very unconcerned) to 7 (very concerned), was used to assess the level of agreement with each of these items.

All respondents were asked to indicate how acceptable it would be to them if PFAS was contained in 13 different products. We focused on a range of products, including those with high-frequency and high-probability use. A Likert scale, ranging from 1 (Very acceptable) to 7 (Very unacceptable) was used.

2.2. Sample characteristics

A total of 1000 responses were collected. After eliminating individuals who answered the survey too fast (<200 s), 935 responses remained. The demographics of the sample are displayed in Appendix 1. We collected a demographically representative sample which ensures that the sample can be considered representative of the population.

2.3. Data analysis

Data was analysed using SPSS (version 26.0). Descriptive statistics were used to provide respondent characteristics. Repeated measures Independent Sample T-tests and ANOVAs were performed to test significant differences between variables, and we reported the Mean (M), and the Standard Deviation (SD). An exploratory factor analysis using principal components factoring (PCA) with varimax rotation was performed for each interested construct: general perceived PFAS knowledge, concerns about the PFAS characteristics, and acceptability of PFAS in consumer products. Kaiser-Meyer-Olkin measure value (KMO) and the Bartlett's test of sphericity result were calculated to explain the variance of the factor(s), while Cronbach's α value was calculated for internal reliability. We also report the Factor Loadings in the associated tables. A Spearman correlation analysis was performed to reveal the relationship among items in each analysis group. The statistical significance of all analyses was set at p -value <0.05 .

3. Results

3.1. Awareness and knowledge of PFAS among survey respondents

Many respondents had not heard of PFAS before (55.2 %), with others while having heard of it, knew nothing (19.8 %) or very little about it (19.6 %), only 4 % knew a lot about PFAS with another 1.5 % specifying they knew a lot through their employment. However, when analysing the open-ended question, which asked respondents to explain what they believed PFAS referred to, many who had answered as knowing a lot about PFAS could not corroborate this. Only 206 of the $n = 443$ who answered they had heard of PFAS before had a relevant or correct answer. The content analysis revealed that the majority related PFAS to: being a chemical ($n = 48$), the concept of it being ‘forever’ ($n = 10$), its non-degradability ($n = 14$), its long lasting properties ($n = 10$), links to it being toxic or harmful ($n = 23$) with some references to human health ($n = 4$) and environmental impact ($n = 2$). Many also related it to plastics, with some confusing it with microplastics ($n = 29$). Others believed it was contained in everyday products ($n = 4$), food ($n = 3$), food packaging ($n = 3$), household appliances ($n = 3$) such as fridges ($n = 2$) or refrigerants ($n = 2$), frying pans or non-stick cookware ($n = 3$), specifically mentioning Teflon ($n = 3$) or its resistance to heat, water, grease, and oil ($n = 4$).

Most respondents heard about PFAS from the internet and television, and very few are learning about PFAS from sources such as environmental (13.4 %) and scientific journals (12.6 %) (Fig. 1).

Our analysis indicates that for those who had previous PFAS knowledge, the majority found it difficult or rather difficult to understand (58.8 %) (Fig. 2). Those who had not heard of PFAS before the survey and were presented with the PFAS information found it rather easy or easy to understand (62 %).

An exploratory factor analysis using PCA (with varimax rotation) was performed for items referring to general perceived knowledge about PFAS. Based on the Kaiser-Meyer-Olkin measure value (KMO = 0.918)

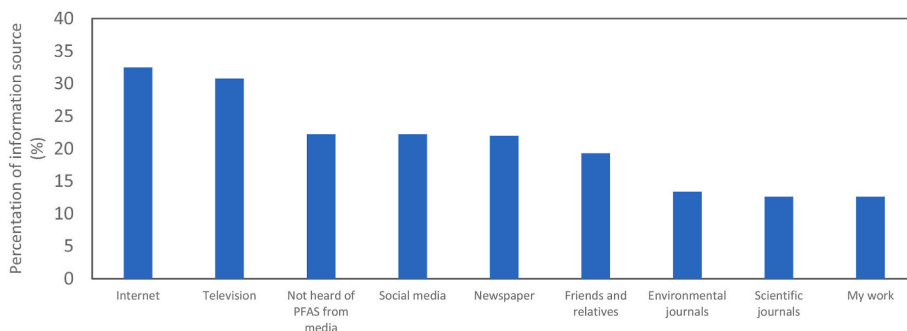


Fig. 1. PFAS information sources of survey respondents (From which sources of information have you heard of PFAS?).

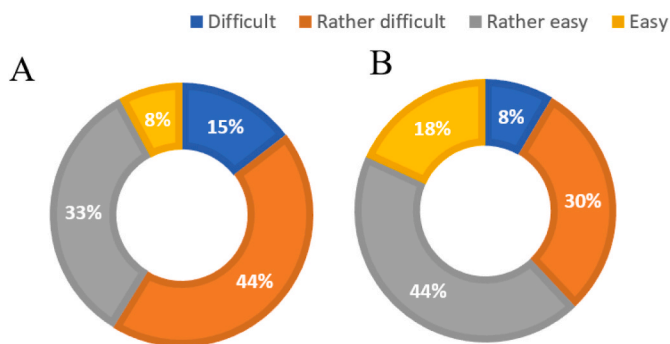


Fig. 2. PFAS knowledge understanding difficulty (In general, do you find the information you have read or heard about PFAS easy to understand, or difficult?). A, respondents with prior PFAS knowledge. B, respondents with no prior knowledge (after the presentation of PFAS information).

and the Bartlett’s test of sphericity result ($\chi^2 = 2182.13$, $df = 10$, $p < 0.001$), a one-factor solution was retained (Cronbach’s $\alpha = 0.957$), explaining 85.38 % of the variance (Table 1). Perceived knowledge was the highest for impact on human health, followed by impact on the environment based on the mean value of each item.

The Independent Samples T-Test analysis showed a significant difference between female and male understanding of PFAS. Males had a greater perceived knowledge ($M = 4.47$) than females ($M = 3.83$) ($F = 0.159$, $p < 0.001$).

A repeated measures ANOVA ($F = 21.50$, $p < 0.001$), followed by pairwise comparisons, showed that younger respondents also indicated greater PFAS knowledge, with 18–24 year olds ($M_{18-24} = 5.22$) indicating more (perceived) knowledge than 35–44 ($M_{35-44} = 4.14$), 45–54 ($M_{45-54} = 3.24$), 55–64 ($M_{55-64} = 3.33$) and 65+ ($M_{65+} = 3.45$), while 25–36 year olds ($M_{25-36} = 4.80$) were more (perceived) knowledgeable than 45–54 ($M_{45-54} = 3.24$), 55–64 ($M_{55-64} = 3.33$) and 65+ ($M_{65+} =$

Table 1
PCA analysis of perceived knowledge of PFAS.

How well do you know the topic PFAS?	M	SD	Factor loadings
I have good knowledge of PFAS as an additive/ingredient in many products	4.17	1.83	0.930
I have a good knowledge on the impacts of PFAS on the environment	4.25	1.81	0.927
I have a good knowledge on how to behave regarding PFAS-containing products	4.17	1.82	0.927
I have a good knowledge on the distribution of PFAS	4.05	1.81	0.923
I have a good knowledge on the impacts of PFAS on human health	4.32	1.81	0.912
Variance explained (%)			85.38
Cronbach Alpha			0.957
Factor	4.19	1.68	
N	409		

3.45).

To examine the correlation between environmental concern and perceived PFAS knowledge an exploratory factor analysis using PCA (with varimax rotation) was performed. Based on the Kaiser-Meyer-Olkin measure value ($KMO = 0.841$) and the Bartlett’s test of sphericity result ($\chi^2 = 1995.62$, $df = 21$, $p < 0.001$) a one-factor solution was retained for environmental concern (Cronbach’s $\alpha = 0.836$), explaining 51.32 % of the variance. A Spearman correlation analysis was performed to assess the linear relationship between environmental concern and perceived PFAS knowledge. The two variables had a positive correlation, $r(365) = 0.480$, $p < 0.001$.

Examining the multichoice question on belief in products containing PFAS, we found that a high number of respondents believed PFAS to be present (Fig. 3) in non-stick frying pan (45.9 %), plastic toys (44.6 %), and carpet (40.9 %), with the least believing this was present in dental floss (22.7 %) and metal cutlery (25.7 %).

Most respondents indicated they wanted to learn more about PFAS ($M = 5.26$, $SD = 1.48$), with many also believing this would make a difference in how they would behave ($M = 5.39$, $SD = 1.40$). The Independent Samples T-Test analysis showed no significant difference between males and females and their desire to learn more about PFAS ($M = 5.32$, $M = 5.30$, $F = 3.38$, $p = 0.23$). However, females indicated ($M = 5.48$) that knowing more about the risks of PFAS would make a difference in how they behave ($F = 0.470$, $p = 0.02$) compared to males ($M = 5.29$). A repeated measures ANOVA, followed by pairwise comparisons, found no significant difference for wanting to know more about PFAS or whether knowing more would impact their behaviour ($F = 1.88$, $p = 0.10$) between age groups.

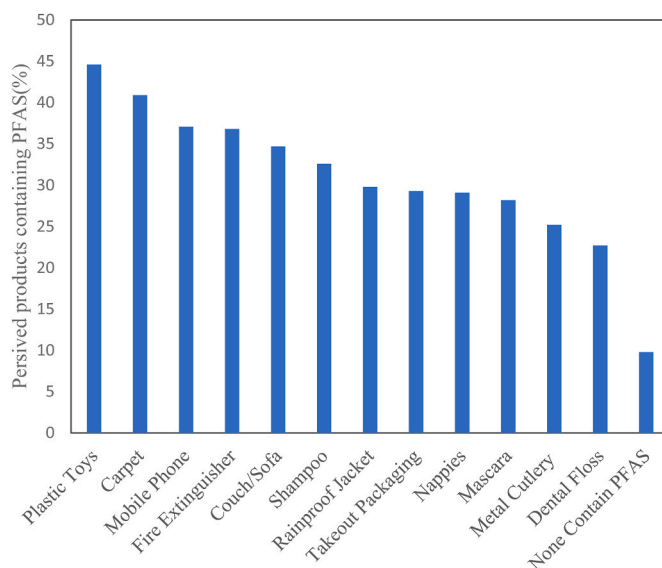


Fig. 3. Perceived products containing PFAS in the survey.

Table 2
PCA analysis of concerns about the characteristics of PFAS.

How concerned are you about the following statements about the characteristics of PFAS?	M	SD	Factor loadings
PFAS accumulate in blood, liver, and other proteinaceous organs and cause various health concerns.	5.64	1.36	0.89
Once PFAS are in the environment, they are very difficult to remove.	5.62	1.35	0.88
PFAS accumulate in the environment and stay there for thousands of years.	5.59	1.41	0.88
PFAS that have accumulated in the body can remain in the body for a long time.	5.58	1.41	0.87
PFAS are everywhere in the environment, even in remote places, such as Arctic and Antarctic.	5.53	1.37	0.88
PFAS are so ubiquitous that they are taken up by many organisms that are food sources for people.	5.51	1.34	0.88
In general, how concerned are you about PFAS?	5.49	1.43	0.88
Since PFAS are not natural substances, ingestion and inhalation introduces artificial substances into the body.	5.48	1.30	0.86
Since some PFAS can be released into air from common indoor items such as carpet and stain-resistant textile, they can also be inhaled.	5.47	1.35	0.88
Variance explained (%)			77.2
Cronbach Alpha			0.96
Factor	5.55	1.21	

Table 3
PCA analysis of the acceptability of PFAS in consumer products.

In general, how acceptable would it be to you if PFAS was contained in the following products?	M	SD	Factor Loadings
Mascara	5.32	1.78	0.89
Metal cutlery	5.32	1.77	0.89
Takeout packaging (i.e., pizza box)	5.22	1.78	0.90
Nappies	5.22	1.77	0.89
Shampoo	5.17	1.78	0.90
Dental floss	5.16	1.75	0.90
Fire extinguisher	5.15	1.78	0.76
Plastic toys	5.10	1.77	0.91
Carpet	5.02	1.71	0.91
Rainproof water jacket	4.97	1.75	0.88
Non-stick frying pan	4.87	1.77	0.89
Couch/sofa	4.78	1.78	0.90
Mobile phone	4.62	1.76	0.87
Variance explained (%)			78.28
Cronbach Alpha			0.98
Factor	5.07	1.56	

The Independent Samples T-Test analysis found that males had a greater belief that the media was reporting enough about PFAS (M = 4.03) compared to females (M = 3.40, F = 1.76, P < 0.001). A repeated measures ANOVA, followed by pairwise comparisons, showed there was a significant difference between age groups for perceptions around the media, with a significant difference between 18 and 24 year olds (M = 4.67) and all age groups (M₂₅₋₃₄ = 3.87, M₃₅₋₄₄ = 3.75, M₄₅₋₅₄ = 3.20, M₅₅₋₆₄ = 3.38, M₆₅₊ = 3.37) as well as between 25 and 34 year olds (M = 3.87) and 45–54 year olds (M = 3.20) (F = 11.39, p < 0.001).

Table 4
PFAS knowledge, acceptability, and concern.

	No knowledge	Low knowledge	Medium knowledge	High knowledge	F	p
N	516	133	131	145		
Acceptability	5.36 ^a	5.69 ^b	5.00 ^c	3.53 ^d	49.75	<0.001
Concern	5.46 ^a	5.82 ^b	5.32 ^a	5.75 ^b	6.48	<0.001
Environmental concern	4.42 ^a	4.83 ^b	4.55 ^{ab}	5.83 ^c	88.17	<0.001

Mean values followed by different letters are significantly different (p < 0.01).

1-7 Likert scale (denoting 1 = very acceptable, 7 = very unacceptable/1 = very unconcerned, 7 = very concerned/1 = Strong disagree, 7 = strongly agree).

3.2. Concern of PFAS

All participants answered questions related to PFAS concern after reading the PFAS information. The PCA retained a one-factor solution (Cronbach's $\alpha = 0.96$) for items referring to concerns about PFAS (KMO = 0.965 and $\chi^2 = 8494.18$, df = 36, p < 0.001) (Table 2). Examining the mean per item, the majority of respondents were concerned about several characteristics of PFAS. The largest number of respondents were concerned about PFAS accumulating in the blood, liver, and other proteinaceous organs (M = 5.64, SD = 1.36). This was followed by the concern that PFAS are so ubiquitous that they are taken up by many organisms that are food sources for people (M = 5.51, SD = 1.34), and the concern that since some PFAS can be released into air from common indoor items such as carpet and stain-resistant textile, they can also be inhaled (5.47, SD = 1.35). Spearman correlation analysis indicated a positive correlation between environmental concern and PFAS concern (r(df) = 0.331, p < 0.001).

The Independent Samples T-Test analysis found a significant difference between female and male concern for PFAS. Females had greater concern (M = 5.75) than males (M = 5.32) (F = 8.154, p < 0.001). A repeated measures ANOVA, followed by pairwise comparisons, found no significant difference in PFAS concern between ages (F = 1.96, p = 0.08).

3.3. Acceptability of PFAS in products

A one-factor solution was retained (Cronbach's $\alpha = 0.98$) in the PCA analysis for items referring to the acceptability of PFAS contained in consumer products (KMO = 0.978, $\chi^2 = 14,973.82$, df = 78, p < 0.001) (Table 3). We found that mascara (M = 5.32, SD = 1.78), metal cutlery (M = 5.32, SD = 1.77), takeout packaging (M = 5.22, SD = 1.78), and nappies (M = 5.22, SD = 1.77) to be the most unacceptable. While mobile phone (M = 4.62, SD = 1.76), sofa/couch (M = 4.78, SD = 1.78) and non-stick frying pan (M = 4.87, SD = 1.77) were found to be the most acceptable products; however, these in general still received very low acceptability ratings. No significant correlations were identified in the Spearman analysis of the relationship between environmental concern and the acceptability of PFAS in consumer products (r(df) = -0.056, p = 0.116).

The T-Test for the acceptability factor showed a significant difference between female and male acceptability ratings of PFAS. Females had less tolerance for PFAS in consumer products (M = 5.47) than males (M = 4.63) (F = 4.80, p < 0.001). A repeated measures ANOVA (F = 29.80, p < 0.001) for the acceptability factor showed that younger respondents were generally more accepting of consumer products containing PFAS. Specifically, 18–24 year olds (M = 3.94) were more accepting than those aged 35–44 (M = 5.30), 45–54 (M = 5.63), 55–64 (M = 5.69) and 65+ (M = 5.30). In addition, 25–36 year olds (M = 4.47) were more accepting than those aged between 35 and 44 (M = 5.30), 45–54 (M = 5.63), 55–64 (M = 5.69) and 65+ (M = 5.30).

3.4. Levels of knowledge and concern

To examine whether the level of knowledge differed between levels of PFAS acceptability in consumer goods, levels of PFAS concern and

Table 5
Demographics differences between PFAS knowledge (Chi-Square).

	No	Low	Neutral	High	Overall sample	χ^2	P
Gender							
Male	214 (41.5)	62 (46.6)	69 (52.7)	97 (66.9)	442 (47.8)	30.79	<0.001
Female	302 (58.5)	71 (53.4)	62 (47.3)	48 (33.1)	483 (52.2)		
Age							
18–24	49 (9.5)	12 (9)	15 (11.5)	56 (38.6)	132 (14.3)	150.62	<0.001
25–34	85 (16.5)	18 (13.5)	26 (19.8)	47 (32.4)	176 (19)		
35–44	113 (21.9)	23 (17.3)	23 (17.6)	26 (17.9)	185 (20)		
45–54	111 (21.5)	28 (21.1)	16 (12.2)	6 (4.1)	161 (17.4)		
55–64	89 (17.2)	29 (21.8)	23 (17.6)	<5	145 (15.7)		
65+	69 (13.4)	23 (17.3)	28 (21.4)	6 (4.1)	126 (13.6)		
Education							
None	45 (9.0)	8 (6)	<5	<5	57 (6.3)	28.76	<0.001
Completed some form of basic (high school) education	141 (28.1)	37 (27.8)	35 (27.8)	33 (22.9)	246 (27.2)		
Tertiary qualification (such as Diploma or Certificate)	135 (26.9)	46 (34.6)	43 (34.1)	53 (36.8)	277 (30.6)		
Bachelor's degree	116 (23.1)	29 (21.8)	36 (28.6)	43 (29.9)	224 (24.8)		
Masters or PhD	65 (12.9)	13 (9.8)	10 (7.9)	13 (9.0)	101 (11.2)		

environmental concern, the level of perceived PFAS knowledge was coded into low (1–3), medium (3.01–5) and high knowledge (5.01–7), while those who indicated they had not heard of PFAS before were coded as ‘no knowledge’ (Table 4). A repeated measures ANOVA ($F = 49.75$, $p < 0.001$) found that acceptability ratings of PFAS contained in products differed between all knowledge groups. Those with the highest level of PFAS knowledge were the most accepting of PFAS-containing products, while those with no knowledge were the least accepting. A repeated measures ANOVA ($F = 6.48$, $p < 0.001$) also found significant differences between the levels of knowledge, namely, those with higher PFAS knowledge perceived high concerns, more so than ‘no’ and ‘medium’ knowledge, but this did not differ from those with ‘low’ knowledge. Similarly, environmental concern differed between some knowledge groups ($F = 88.17$, $p < 0.001$) with high knowledge individuals the most concerned out of all groups.

In addition, through several repeated chi-square tests, we found that certain demographic characteristics were overrepresented for the level of perceived PFAS knowledge (Table 5). Males were more likely to indicate high perceived knowledge, while females were more likely to have not heard of PFAS. Younger respondents (18–24 and 25–34) were more likely to indicate high perceived knowledge, while older respondents (35 and older) were more likely to have not heard of PFAS. Those with lower education (no high education and high school education) were more likely to have not heard of PFAS, while those who had completed a Polytech degree or diploma, still studying tertiary or hold a Bachelor's degree were more likely to indicate high perceived knowledge. However, those holding a Master's or Ph.D. were more likely to have not heard of PFAS.

4. Discussion

PFAS has gained the international attention of concerned scientists and regulators. However, we know very little about the knowledge and concern of the general population. The implementation of regulations and policies for PFAS requires political will and actual commitment (Lin et al., 2019). When there are high levels of public awareness and concern about consumer products and their impact on health, the resultant pressure felt by the government and industry could feasibly lead to a performance of action via viable political and industry commitments to PFAS regulation and mitigation (Bahk et al., 2013; Glass et al., 2017). In this research, we aimed to understand the general public's knowledge and concern about PFAS in Aotearoa, New Zealand where the public population has low exposure to PFAS contamination events (Lenka et al., 2022) and media coverage. The results of this study will help inform future education campaigns, policies, and consumer product manufacture.

Overall, this study found that nearly 45 % of the participants have heard of PFAS. Yet, less than half of those who indicated previous knowledge noted some level of correct qualitative evidence of their understanding, even though most of these respondents believed they had a good understanding of PFAS. Considering most respondents heard about PFAS from the internet and television, with little learning from peer-reviewed sources such as academic or research journals, there may be misunderstandings about PFAS, or the information conveyed might be more aggressively politicised in ways that sway attitudes or concerns. Many respondents did express a wish to learn more about PFAS, believing this would impact their behaviour. Effective education of the public on PFAS will depend on the medium of delivery and the choice of content. The research findings indicate that for those who had previous PFAS knowledge, the majority found PFAS information difficult or rather difficult to understand, which was reversed for those who had not heard of PFAS before the survey (and were presented this question after they had read the PFAS information). This may demonstrate that our PFAS information sheet was relatively easy for individuals to understand.

The research findings also indicate that individuals with the greatest PFAS knowledge (vs no knowledge) had more PFAS concern but simultaneously more acceptance of PFAS-containing products. This might point to more acceptability around ‘known unknowns’ and concern for ‘unknown unknowns’ with regard to complex environmental problems (e.g., Chaudhry et al., 2010). Research frequently finds that there is a weak correlation between perceived and factual knowledge (Alba and Hutchinson, 2000; Carlson et al., 2009). Thus, while the research findings demonstrate greater perceived PFAS knowledge may lead to greater concern but more tolerance for PFAS contamination, this does not necessarily mean individuals will act differently in their purchase (or use) behaviour (Ajzen et al., 2011).

A high level of concern was seen for PFAS. Previous research also shows a high level of concern, with 60 % of Wisconsin residents concerned about PFAS contamination in their drinking water. Our study found that respondents believed that PFAS contained in mascara, metal cutlery, takeout packaging and nappies the most unacceptable, while mobile phone, sofa/couch and non-stick frying pan were found to be the most acceptable products. Yet, overall, most consumer products rated still received very low acceptability ratings. These findings suggest that consumer products ‘closer’ to the consumer, such as products that touch skin or those more likely to be consumed orally are more likely to be seen as unacceptable. Similarly, research on contamination and disgust finds that reactions to products intended for intimate use or internalised are strongly negative (Abbey et al., 2015).

The research also aimed to understand the demographic factors differentiating PFAS concerns and knowledge. We found that males

were found to be more knowledgeable (perceived) and less concerned than females, while females had less tolerance for PFAS in consumer products than males. This is in line with previous research, males were found to be twice as likely than females to have heard of PFAS (Wichowsky, 2023), while women expressed greater PFAS concern (Wichowsky, 2023), negative opinions and concerns about PFAS (Stolle and Longworth, 2020). Other research also demonstrates that males tend to be more confident in their science skills and knowledge (McCright, 2010), show less environmental concern (Sundström and McCright, 2014) and worry less about risks (Brown et al., 2021; Gustafson, 1998). Moreover, the study found that younger respondents (aged 18–34 years old) were more likely to indicate high perceived knowledge, while older respondents (35 and older) were more likely to have not heard of PFAS. In addition, younger respondents were generally more accepting of consumer products containing PFAS. However, there was no significant difference in PFAS concern *between* ages. Such a finding may relate to younger adults being less risk averse, as demonstrated in previous studies (Albert and Duffy, 2012; Rolison et al., 2012). Older adults, in contrast, have been found to see more risk in behaviours related to health and ethics (Bonem et al., 2015). However, while the study finds that younger people perceive themselves as more knowledgeable about PFAS, they are not more concerned than older individuals. Perhaps unsurprisingly, the study found that individuals with greater environmental concern were associated with being more (perceived) knowledgeable and concerned about PFAS. This finding is in line with previous research which indicates that highly environmentally concerned individuals have greater environmental knowledge, beliefs, and behavioural intentions (Pagiaslis and Krontalis, 2014). Lastly, the research findings suggest individuals with a Masters or Ph.D. degree were less likely to indicate high PFAS knowledge. It may be that those who are more highly educated are more aware of what they 'know' and thus, are more honest in their answers, or possibly, they have limited time to read anything extracurricular. As discussed previously, while many indicated they had heard of PFAS before, the qualitative research indicated a lack of actual knowledge.

4.1. Implications and recommendations

Organisations should heed that there is increasing concern and less tolerance for PFAS. Manufacturers of consumer products with intentionally added PFAS must be aware of how negative perceptions may reflect on their corporate reputation. Research increasingly demonstrates the importance of social and environmental values in purchase behaviour (Deloitte, 2021), with evidence of individuals willing to boycott or attack companies (Kähr et al., 2016), which knowingly perpetuate health or environmental issues. Recommendations for companies dealing with PFAS products is to provide information to their customers about its use and risks. Alternatively, marketers and producers of no additionally added PFAS products should explore opportunities for communicating this characteristic to appeal to those who wish to reduce their PFAS exposure.

Companies aiming to eliminate intentionally added PFAS should take note of the need for education. We highlight the need for education to allow greater transparency but also possibly alleviate people's fears. The findings suggest that regulators and (non)governmental agencies hoping to increase PFAS awareness and knowledge could take opportunities to digest robust and scientifically informed research about PFAS and create easy to understand, accessible information for the public, which it appears, would be welcomed. Recommendations include disseminating information via credible agencies and various mediums, such as social media and newspaper articles, in order to appeal to different demographics. Our findings on the demographic differences provide insight into how to target (segment/group) certain populations. For example, campaigns targeted at younger or older and different genders often use varied mediums (e.g., TikTok for younger consumers, Facebook for older consumers) and messages (e.g., some audiences may

wish to know background information, others wish to know which products contain added PFAS). Regardless of what information is presented (Holmquist et al., 2018), the content must also be easily accessible and trustworthy. Tian et al. (2022) found that social media users seek trusted information sources to understand PFAS-related public health efforts, who is in charge and what is being done.

4.2. Limitations and future research

The limitations of the study should be acknowledged but may provide opportunities for future research. First, the study used a market research panel, and a self-administered questionnaire may result in some response bias. As perception research is based on self-report measures, future research may wish to conduct qualitative research on individual understandings and concerns in a more holistic and in-depth manner. Second, the research was conducted in New Zealand, which is unlikely to be applicable to the locales in the E.U. and the U.S., as media coverage (at least regulation) of PFAS has been more widespread. However, other countries may be more or less similar to New Zealand in their PFAS awareness.

Our findings provide several avenues for future research. While respondents revealed general knowledge of PFAS to a certain extent, future research should examine the specific differences between perceived and actual knowledge; for example, the research revealed that a conflation of PFAS and microplastics, or plastics in general, existed. Further research is needed on how individuals manage PFAS concern, for example, does this result in the avoidance of certain products, product categories or brands? We must consider that alternatives are not always available on the market or may be unavailable or inaccessible (i.e., the price to substitute PFAS is too high to make the product accessible in its usual markets). Thus, there is a concern about what people can 'do' to address their concerns about PFAS. For example, consider issues around climate change, where many people feel hopeless and helpless when making life decisions and purchasing decisions resulting in climate- or eco-anxiety (Verplanken et al., 2020). In this vein, future research should examine the actions of those with PFAS concerns. Moreover, communities affected by PFAS often feel uninformed and excluded from (proposed) solutions. Thus, more research should focus on how stakeholders, including the public, are involved in the discussion for remediation (Tian et al., 2022).

4.3. Summary

Our aim was to understand the general public's knowledge and concern about PFAS in Aotearoa New Zealand. Our findings demonstrate that PFAS are known to a almost half of the survey participants, yet, with misunderstandings. Amongst those aware of PFAS, the concern is high, especially for their use in products that contact skin or are consumed orally. Individuals with the highest level of self-perceived PFAS knowledge (vs no knowledge) were most concerned but also the most accepting of PFAS-containing products. Our results also find demographic differences for gender and age. Males were self-perceived to be more knowledgeable and less concerned than females. Younger adults (aged 18–34) were more likely to indicate high perceived knowledge and more acceptance of consumer products containing PFAS than older adults. Our research findings provide insight and recommendations for policy makers and manufacturers, suggesting the need for further consumer education to increase the knowledge about PFAS and PFAS product information provided to customers. All of this information needs to be based on a targeted approach, providing content in a variety of formats and mediums.

CRedit authorship contribution statement

Joya A. Kemper: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft, Visualization.

Emma Sharp: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Shan Yi:** Conceptualization, Methodology, Writing – review & editing. **Erin M. Leitao:** Conceptualization, Methodology, Writing – review & editing. **Lokesh P. Padhye:** Conceptualization, Methodology, Writing – review & editing. **Melanie Kah:** Conceptualization, Methodology, Writing – review & editing. **Jack L.-Y. Chen:** Conceptualization, Methodology, Writing – review & editing. **Kapish Gobindlal:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

Data availability

The data that has been used is confidential.

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This work has received approval for research ethics from University of Auckland and a proof/certificate of approval is available upon request.

Appendix A

Table A1
Demographic composition of the survey participants.

Demographics	% in this survey
Gender	
Females	52.2
Males	47.8
Age	
18–24	14.3
25–34	18.8
35–44	19.8
45–54	17.8
55–64	15.7
65+	13.6
Ethnicity	
Pakeha/NZ European	75.2
Māori	14.7
Chinese	3.1
Indian	3.7
Other Asian	4.9
Education	
Completed some form of basic (high school) education	24.1
Tertiary qualification (such as Diploma or Certificate)	23.7
Bachelor's degree	33.2
Masters or PhD	10.8
Children at home	
None	55.1
One child	24.8
Two children	12.5
Three or more children	7.2

Appendix B

PFAS Information Provided to all

Per and polyfluoroalkyl substances (PFAS), also known as forever chemicals, are a group of widely used, long lasting chemicals, components of which break down very slowly over time.

Because of their widespread use and their persistence in the environment, many PFAS are found in the blood of people and animals all over the world and are present at low levels in a variety of food products and in the environment.

PFAS are found in water, air, fish, and soil at locations across the nation and the globe.

Scientific studies have shown that exposure to some PFAS in the environment may be linked to adverse health effects in humans and animals.

PFAS are resistant to water, oil, and heat. They have been used to make a range of products such as: household items, personal care products, cleaning products, and industrial products including metal plating and specialist firefighting foams.

Exposure to these compounds has been linked to a number of health concerns:

Cancer: PFAS induce tumors in laboratory animals, and the International Agency for Research on Cancer has designated PFOA as a possible carcinogen based on epidemiological evidence linking exposure to kidney and testicular cancer.

Hormone disruption: laboratory tests indicate numerous PFAS affect hormone production and response, with effects on estrogen production and response, thyroid hormone signaling, and on receptors involved in regulation of fat metabolism. People exposed to higher levels of PFAS have higher total and LDL cholesterol.

Liver and kidney toxicity: PFAS are associated with multiple effects on liver and kidney, including liver lesions, kidney degeneration, and

damage to liver function.

Harm to the immune system: Research has identified the immune system as sensitive to PFAS in both laboratory and epidemiological studies. A 2012 study of 587 children found those with greater exposure to PFAS had significantly poorer responses to vaccines.

Reproductive and developmental toxicity: Laboratory tests associated PFAS exposure with decreased survival of young, disrupted reproductive cycles, and impaired growth of the uterus and ovaries. In addition, a number of large epidemiological studies have related higher maternal exposure to PFAS to lower birth weight. A study published in April 2020 reported that PFAS exposure from drinking contaminated water was associated with a higher chance of low birth weight, pre-term birth, and lowered general fertility, and that the differences moderated after PFAS was filtered from the water, providing evidence of a causal link between PFAS and reproductive impacts.

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