Uptake of Per- and Polyfluoroalkyl Substances (PFASs) in *Cannabis sativa*

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Introduction

- PFAS are man-made, aliphatic, fluorinated compounds
- C-F bonds makes them inert to environmental breakdown or metabolism
  - Bioaccumulate in the body, binding to human serum albumin (HSA), storing in the liver and kidneys [1]
- Ubiquitous in the environment – found in blood serum of 90% of Americans [2]
- Exposure → thyroid disease, metabolic imbalances, and cancer [3]
- Agricultural products are a significant route of exposure to PFAS
  - No peer-reviewed publications that examine cannabis uptake of PFAS

Class	PFAS	Acronym
Carboxylic Acid (PFCA)	Perfluorobutanoic acid	PFBA
	Perfluoropentanoic acid	PFPeA
	Perfluorooctanoic acid	PFOA
Sulfonic Acid (PFSA)	Perfluoroethane sulfonate	PFEtS
	Perfluorobutane sulfonate	PFBS
	Perfluorooctane sulfonate	PFOS

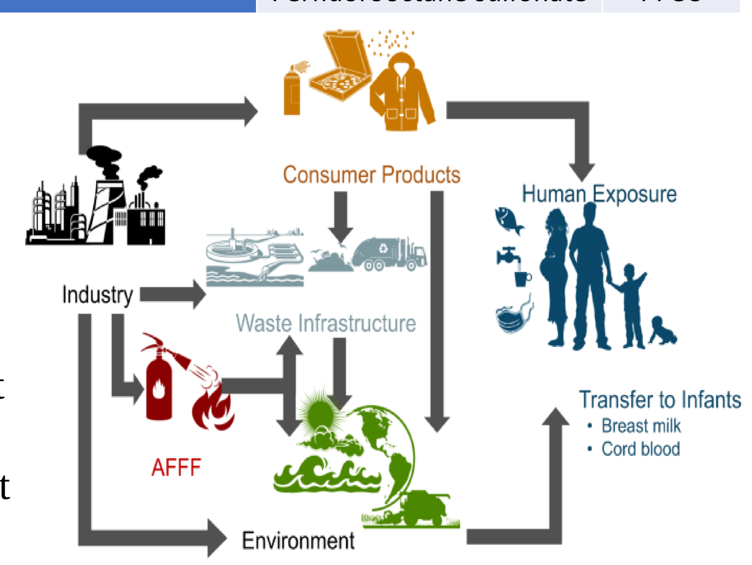
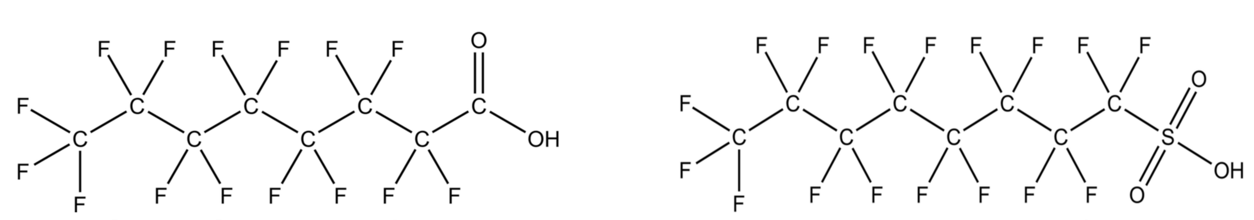


Figure 1. Conceptual model of PFAS exposure [4]

- This literature-based review aims to call to attention the threat PFAS poses to cannabis products and to fill the gaps in knowledge that exist within the cannabis industry and PFAS research



Chemical structure of PFOA

Chemical Structure of PFOS

Methods

- Literature search was broken down into five categories to sharpen the focus of the search
- Online journal databases such as ACS Publications and Google Scholar were used to find pertinent publications
- Key search words were used in each category to refine the search (**Table 1**)
- Exclusionary criteria:
  - Year of publication
  - Quality of methods implemented for growing

Table 1. Categories and search words/phrases for literature search. "PFAS" or "of PFAS" was included either before or after each word or phrase.

Category:	Key search word or phrase:
Chemistry of PFAS	Physical properties ; Chemical Properties ; Thermal degradation ; Thermal breakdown products ; Molecular stability
Environmental Impacts of PFAS Pollution	Pollution scope ; Environmental impact ; Pervasiveness ; Ecological impact ; Half-life exposure
Human Health Outcomes upon PFAS Exposure	Toxicity ; Adverse outcomes ; Mechanism ; Bioaccumulation ; Target organs ; Routes of exposure
Plant Uptake of PFAS	Plant Uptake ; Mechanism of uptake ; Cannabis/marijuana/hemp uptake ; Bioaccumulation ; Translocation ; Vegetable uptake ; Crop uptake ; Ingestion exposure
Phytotoxic Effects upon PFAS Exposure	Phytotoxicity ; Metabolic response to plant exposure

Results

- Exposure
  - Dietary intake found to be the most common route of PFAS exposure. (**Figure 2**)
  - Plants can uptake PFAS from their environment (i.e., soil, groundwater, irrigation water, atmospheric deposition)
- Environmental Mobility
  - Carbon chain length, soil pH, and soil organic matter (SOM) are the most important factors in determining the mobility of PFAS in soil
  - An upward trend of root concentration factor (RCF) with increasing chain length is observed (**Figure 3**)
    - Indicates that shorter chain PFAS are more poorly retained in roots than longer chain PFAS
  - A downward trend of translocation factor (TF) with increasing chain length is observed (**Figure 4**)
    - Indicates that shorter chain PFAS are more readily translocated from the roots to other portions of the plant than longer chain PFAS
- Plant Uptake
  - **Figure 5** shows shorter chain PFAS are more likely to be translocated to the edible portions of plants, whereas longer chain PFAS tend to stay in the roots and stems
  - Irrigation water is a unique route of exposure to long chain PFAS, as they tend to remain wherever they are absorbed

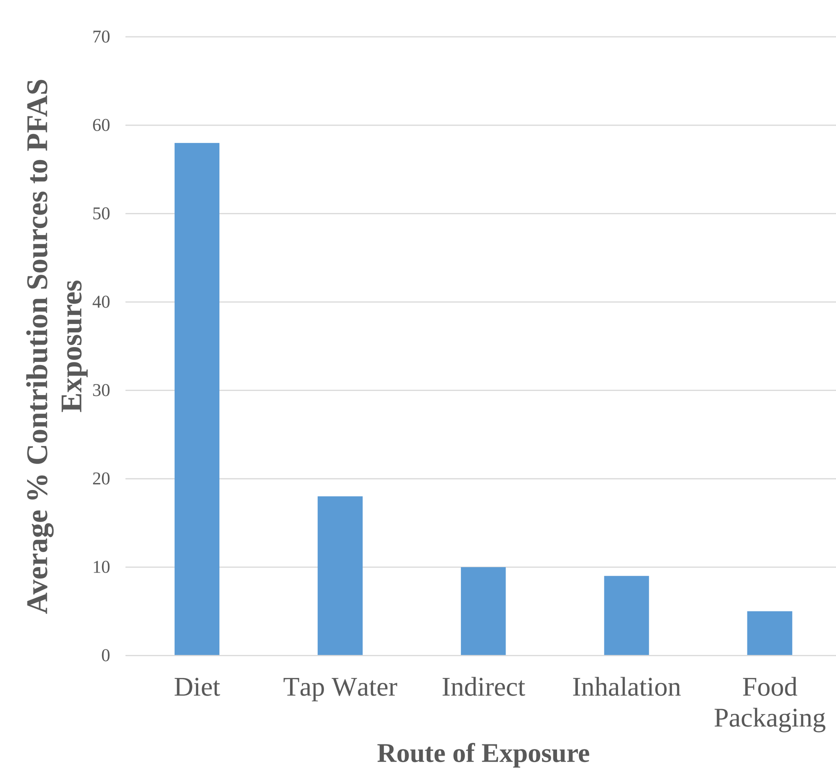


Figure 2. Estimates on the contribution sources (%) to PFAS exposures [5-7]

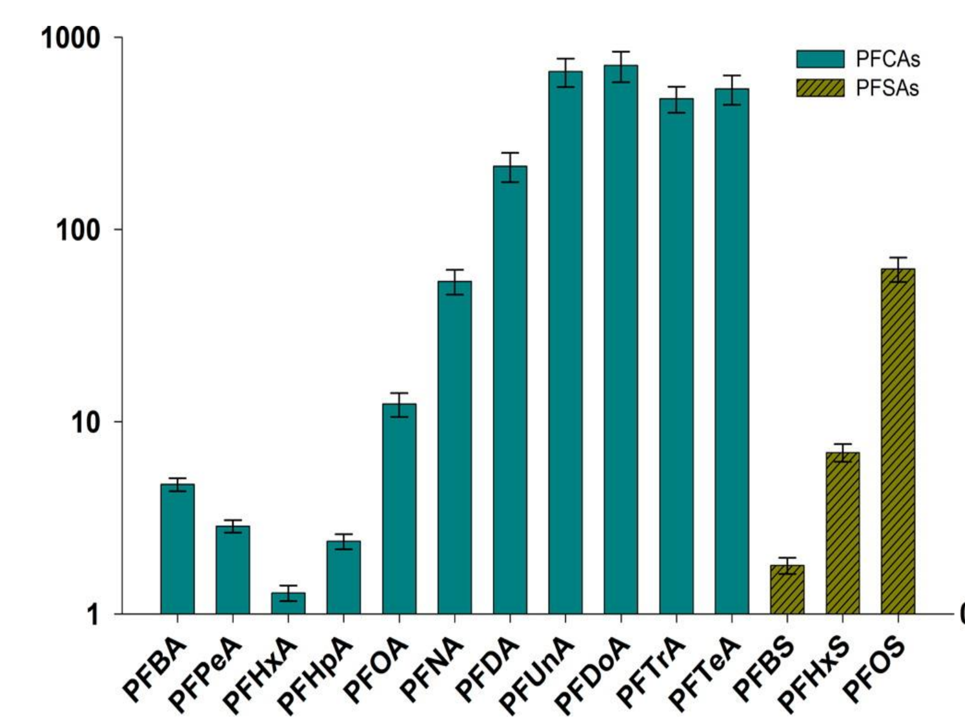


Figure 3. Log scale RCF of 11 PFCA and 3 PFSA. In order of shortest to longest carbon chain for each group, going left to right (starting with 4 carbons with PFBA and going up by one for each bar). RCF is defined as the ratio of root to soil concentration.[8]

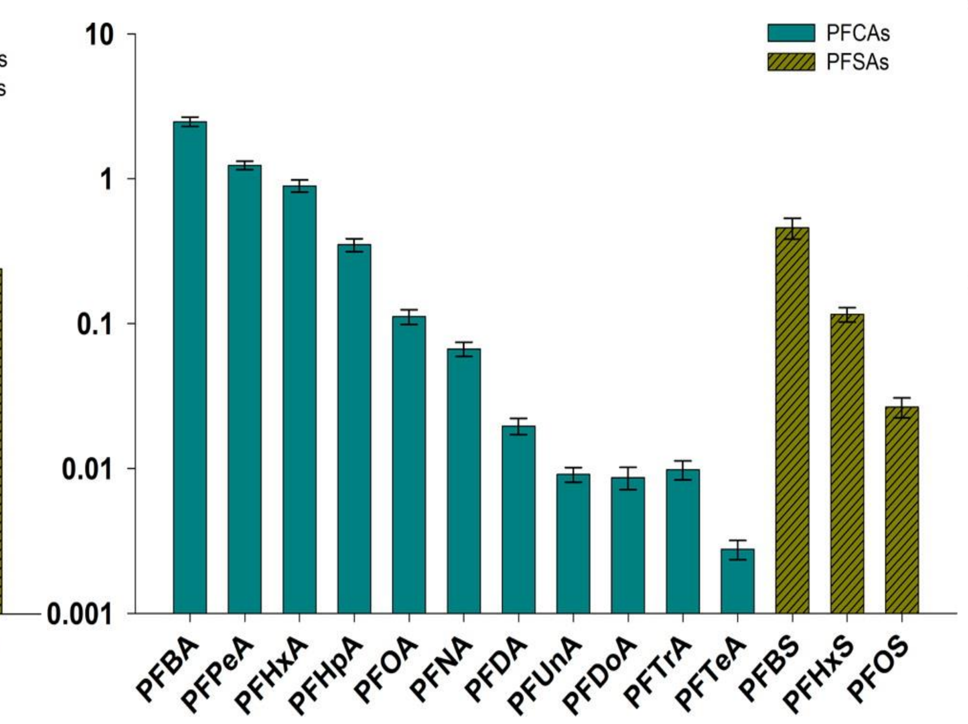


Figure 4. Average TF of 11 PFCA and 3 PFSA. In order of shortest to longest carbon chain for each group, going left to right (starting with 4 carbons with PFBA and going up by one for each bar). TF is defined as the ratio of shoot to root concentration.[8]

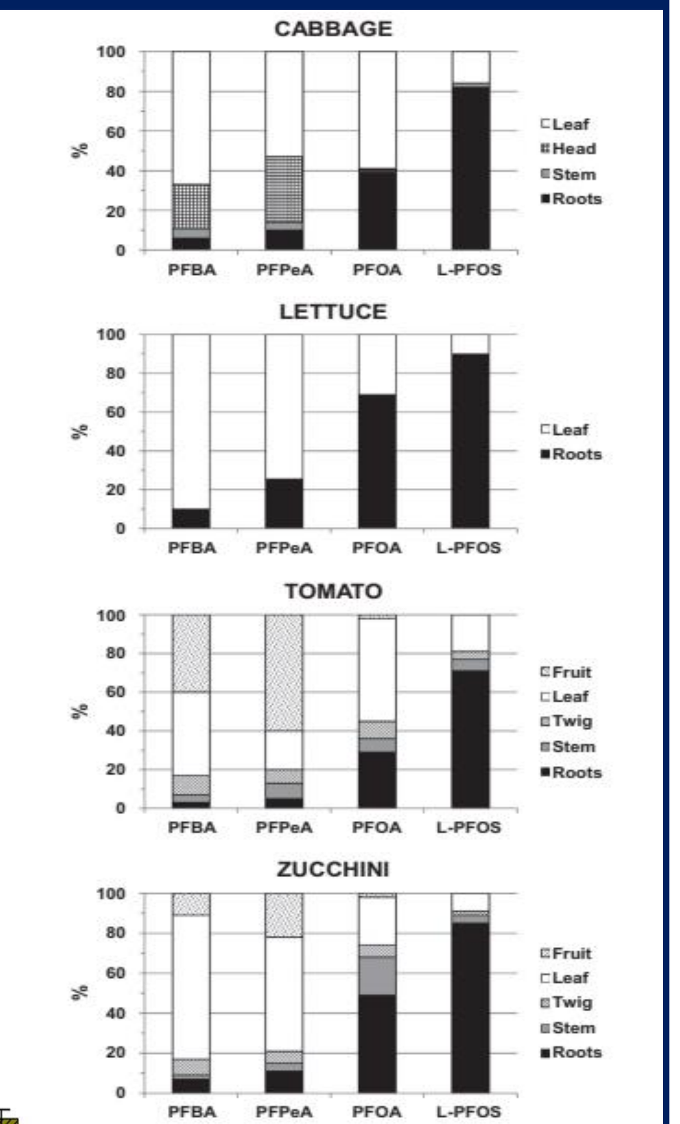


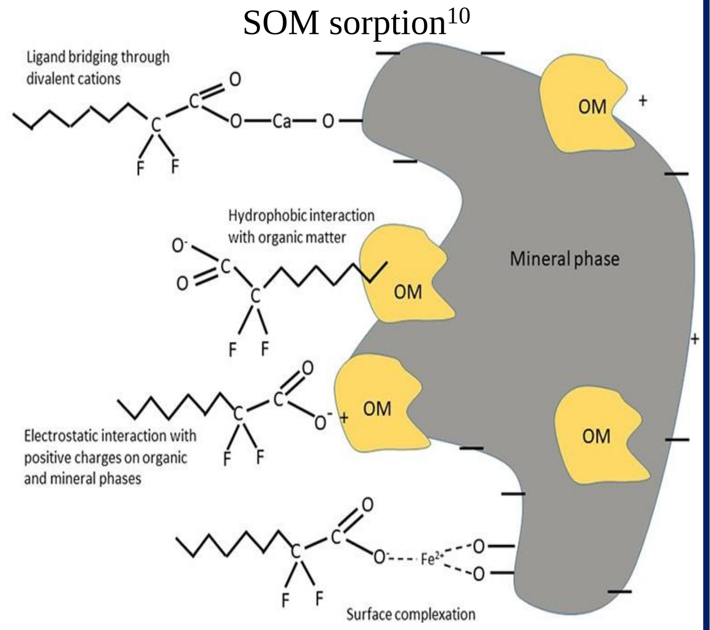
Figure 5. Mass distribution of PFAS in plant tissues of four plants. Expressed as a percent of the total amount of PFAS found in the plant. Increasing chain length is seen going from left to right. In each instance, an upward trend of percentage of total PFAS found in the roots is seen with increasing chain length.[9]

Discussion

- Previous PFAS research has been focused on drinking water, the research herein suggests dietary intake is of greater concern
- PFAS contamination of cannabis products is both possible and likely
  - Long chain PFAS are less bioavailable, but more persistent
  - Short chain PFAS are more bioavailable, but less persistent
- *Cannabis sativa* has an especially aggressive root system; uptake may be of more concern than household vegetables

- Research going forward:
  - Analytical methods for detecting PFAS in cannabis matrices
  - Plant specific uptake patterns, mechanisms, and soil mobility of PFAS (**Figure 6**)
  - Atmospheric deposition of PFAS
  - Hexafluoropropylene oxide dimer acid fluoride, or GenX

Figure 6. Conceptual model of PFAS SOM sorption[10]



Conclusion

- PFAS is a known and pervasive persistent organic pollutant
  - Found in many everyday products, soil, groundwater, and drinking water
- PFAS exposure leads to adverse health outcomes in humans and plants
- Dietary intake is the number one route of exposure to PFAS
- PFAS readily taken up by agricultural goods
- No peer-reviewed publications on uptake of PFAS by *Cannabis sativa*

- As the cannabis market grows rapidly in the United States, research must be done to better understand the threat PFAS poses to cannabis products

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