PFAS Uptake in Food Crops from Compost and Domestic Wastewater: A Field Study

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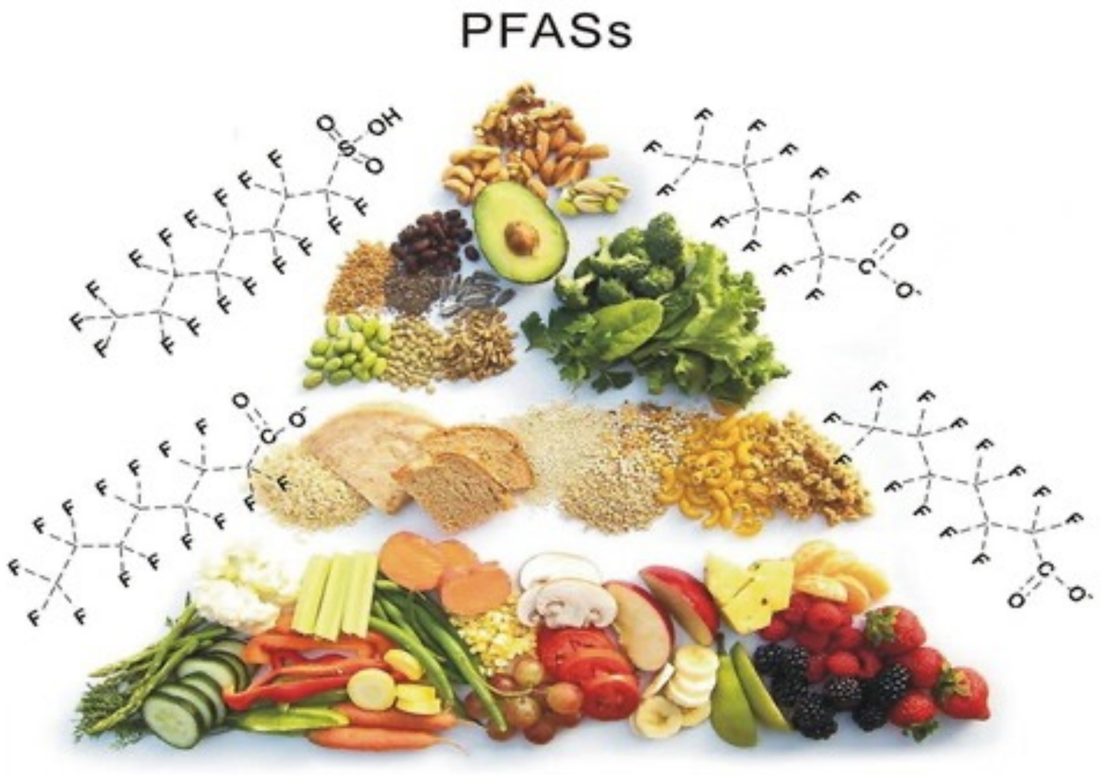


The main questions addressed here:

Hawai‘i has limited water for drinking and irrigation.

1) Hence, is R1 water (recycled-disinfected) safe for agricultural irrigation, in terms of PFAS toxicity?

   If yes:

   -More freshwater for drinking

   -Help the community and the state's agricultural industry.

NOTE: Currently, R1 water is only used to irrigate lawns and golf courses in Hawai‘i.

The main questions addressed here:

Hawai‘i also has a waste/landfill problem (limited land).

There are community initiatives to use more compostable service wares.

2) Hence, is compost made from PFAS-containing compostable service wares safe in terms of PFAS uptake in agricultural crops?

Previous plant uptake studies:

Previous studies only focused on long chain and short chain PFAS (no ultra shorts; C < 4).

L. Lesmeister, F.T. Lange, J. Breuer et al.

Table 1

Incremental decreases Δ log BAFs per perfluorinated carbon atom from linear regression through log BAFs as indicated in literature.

Reference	Culture	Compartment	Δ log BAF (PFCAs)	Range	Δ log BAF (PFSAs)	Range
Yoo et al., 2011	tall fescue+barley+Bermuda grass+Kentucky bluegrass	Shoot	-0.24	C6-C14		
Blaine et al., 2013	lettuce (greenhouse)		-0.32[a]; -0.31[b]	C4-C10	-0.29[a]; -0.28[b]	C4,C6,C8
	lettuce (field)		-0.4	C4-C10		
	tomato (greenhouse)		-0.5[b] to -0.9[b]	C5-C10		
	tomato (field)		-0.1 to -0.3	C4-C10		
Blaine et al., 2014a	radish (greenhouse)	Shoot	-0.11	C4-C10		
		Roots	-0.12	C4-C10		
	celery (greenhouse)	Shoot	-0.36	C4-C10		
		Roots	-0.17	C4-C10		
	tomato (greenhouse)	Shoot	-0.20	C4-C10		
		Fruit	-0.54	C4-C10		
		Roots	not significant	C4-C10		
	pea (greenhouse)	Shoot	-0.30	C4-C10		
		Fruit	-0.58	C4-C10		
		Roots	not significant	C4-C10		
Blaine et al., 2014b	strawberry (greenhouse)	Fruit	-0.29	C4-C9		
		Shoot	-0.17	C4-C9		
		Roots	-0.31	C4-C9		
	lettuce (greenhouse)		-0.43 to -0.70	C4-C9		
Liu et al., 2017	wheat (field)	Grains	-0.52	C4-C8		
	maize (field)	Grains	-0.52	C4-C8		
Liu et al., 2019	Radish+Carrot (field)	Roots	-0.28[c]; -0.25[d]	C4-C8		
	7 Shoot vegetables (field)	Shoot	-0.23[c]; -0.10[d]	C4-C8		
	Cauliflower (field)	Edible part	-0.37[c]; -0.25[d]	C4-C8		
	Pepper (field)	Fruit	-0.60[c]; -0.31[d]	C4-C8		
	Wheat+Corn+Soybean (field)	Grains	-0.79[c]; -0.36[d]	C4-C8		
	Celery (field)	Shoot	-0.34[c]	C4-C8		
	Pumpkin (field)	Fruit	-0.71[c]	C4-C8		
	Soybean (field)	Grains	-1.16[c]	C4-C8		
Lasee et al., 2019	Radish (greenhouse)	Shoot	-0.27	C7-C9	-0.21	C4,C6,C8
		Roots	-0.42	C7-C9	-0.35	C4,C6,C8
	carrot (greenhouse)	Shoot	-0.52	C7-C9	-0.10	C4,C6,C8
		Roots	-0.66	C7-C9	-0.19	C4,C6,C8
	alfalfa (greenhouse)	Shoot	-0.87	C7-C9	-0.47	C4,C6,C8
		Roots	-0.48	C7-C9	-0.23	C4,C6,C8
Gredelj et al., 2020b	chicory (greenhouse)	Shoot	-0.27[e]; -0.28[f]; -0.31[g]	C4-C10		
		Roots	-0.26[e]; -0.31[f]; -0.32[g]	C4-C10		

The table is only considering log BAFs from soil to respective compartments, no translocation between different compartments or BAFs from hydroponic cultures. Radish: no actual investigation of the roots but rather of the hypocotyl (unclear for Lasee et al., 2019).

[a] soil impacted with industrial biosolids
[b] soil impacted with municipal biosolids
[c] 0.3 km distance from fluorochemical industrial park
[d] 10 km distance from fluorochemical industrial park
[e] spiked irrigation water
[f] spiked soil
[g] spiked soil and spiked irrigation water

Reference:

Lesmeister, L., Lange, F. T., Breuer, J., Biegel-Engler, A., Giese, E., & Scheurer, M. (2021). Extending the knowledge about PFAS bioaccumulation factors for agricultural plants - A review. *The Science of the total environment*, *766*, 142640. https://doi.org/10.1016/j.scitotenv.2020.142640

Ultra-short PFAS (< 4Cs)

Perfluoro-ethanoate ($PFEtA^-$) and perfluoro-propanoate ($PFPrA^-$) are the most common ultra shorts involved in plant uptake.

They are both water soluble.

They both can be breakdown products of long/short chain PFAS.

The state of Hawai‘i has Environmental Action Levels (EALs) for $PFEtA^-$ and $PFPrA^-$.

Although ultra short PFAS are less toxic, in high concentrations (during accumulation) they are still very toxic.

Reference:

Lesmeister, L., Lange, F. T., Breuer, J., Biegel-Engler, A., Giese, E., & Scheurer, M. (2021). Extending the knowledge about PFAS bioaccumulation factors for agricultural plants - A review. *The Science of the total environment*, *766*, 142640. https://doi.org/10.1016/j.scitotenv.2020.142640

The state of Hawaiʻi is interested in "Total PFAS' Risk"

Total PFAS' Risk =

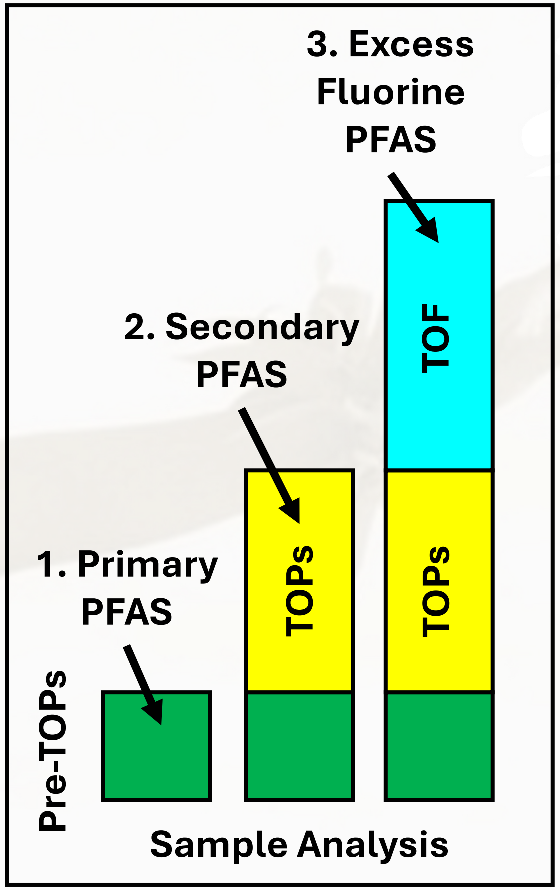
Primary Terminal PFAS' Risk +
Secondary Terminal PFASs Risk +
Excess Fluorine PFAS' Risk

Or

Risk associated with long-chain + short-chain + ultra-short chain PFAS

Or

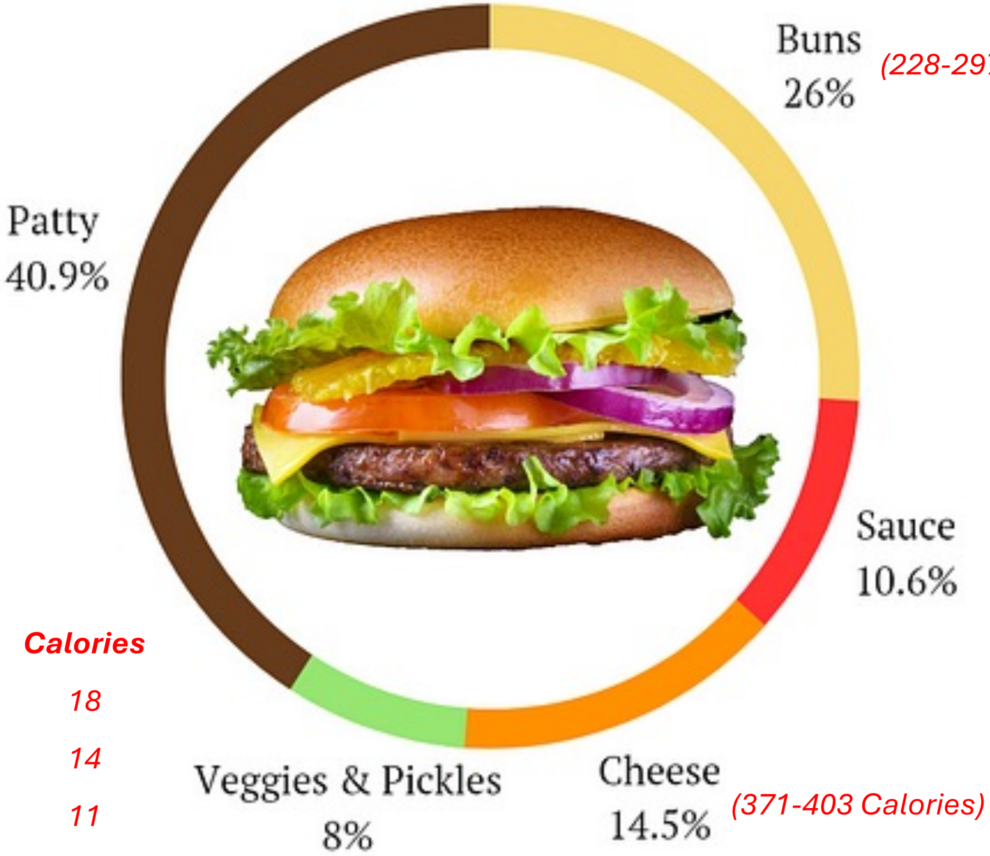
Pre-TOPs + Post-TOPs + TOFs



TOPs = Total Organic Precursors

TOFs = Total Organic Fluorine

E.g.,
How do you calculate the total calories in a burger?



(228-297 Calories) (Buns)

(254-314 Calories) (Patty)

(371-403 Calories) (Cheese)

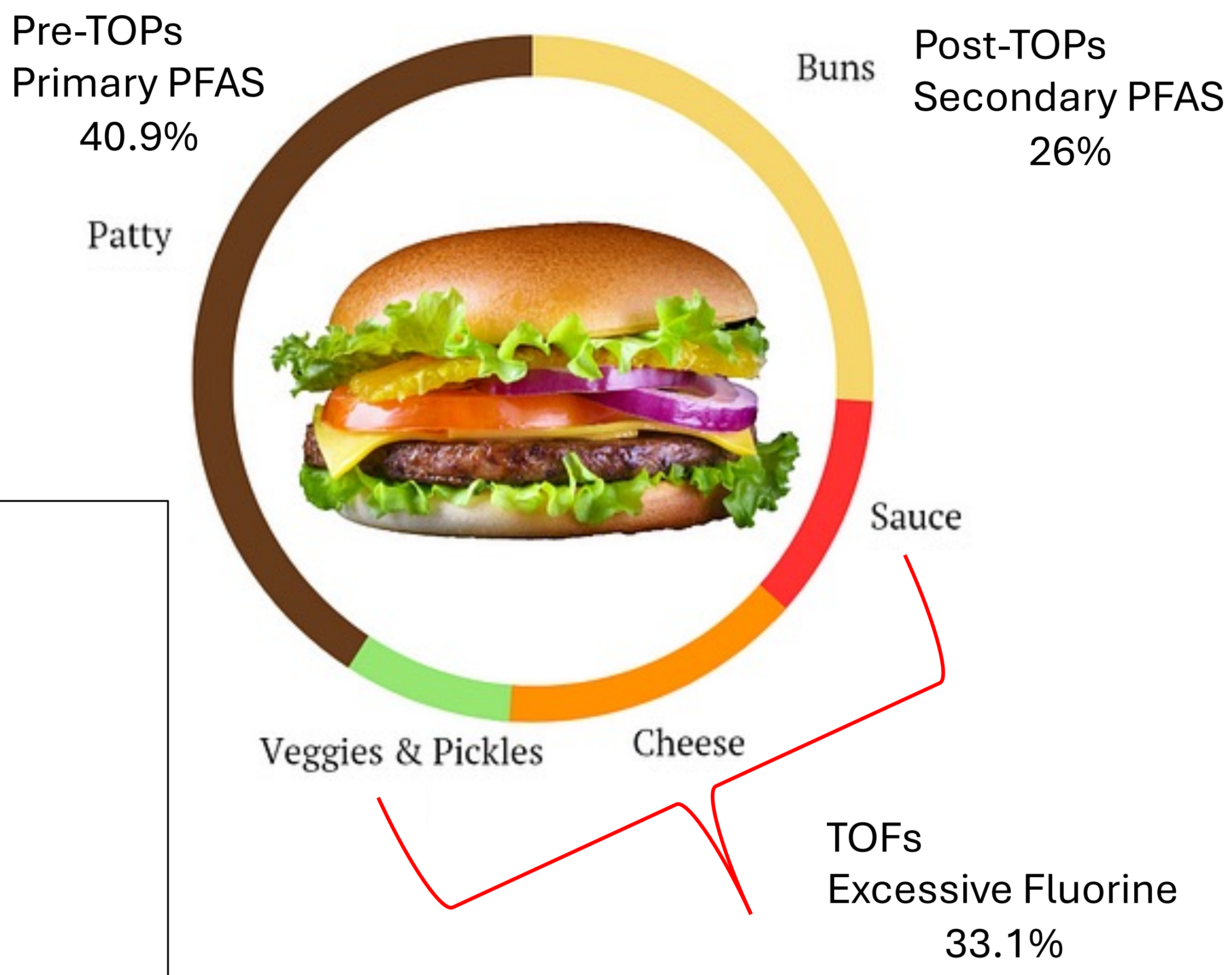
Sauce	***Calories***
Mustard	*53*
Ketchup	*15*
Mayo	*57*

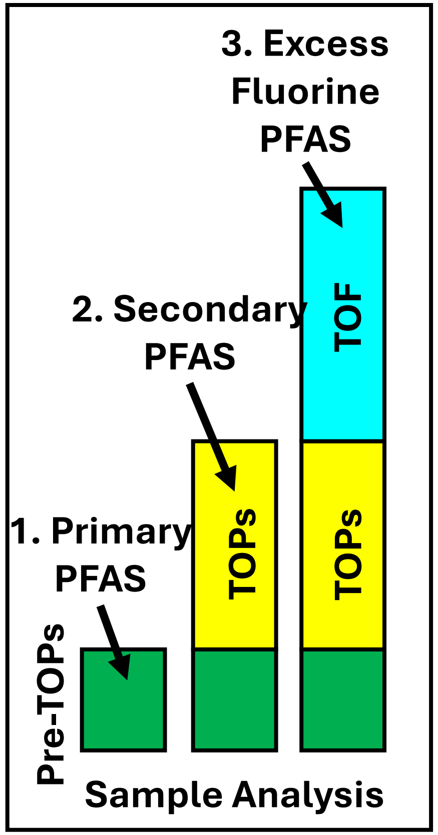
**Per 1 Tablespoon*

Veggies	***Calories***
Tomatoes	*18*
Lettuce	*14*
Pickles	*11*
Onions	*40*

**Per 100 grams*

Now, replace total calories with risk associated with PFAS





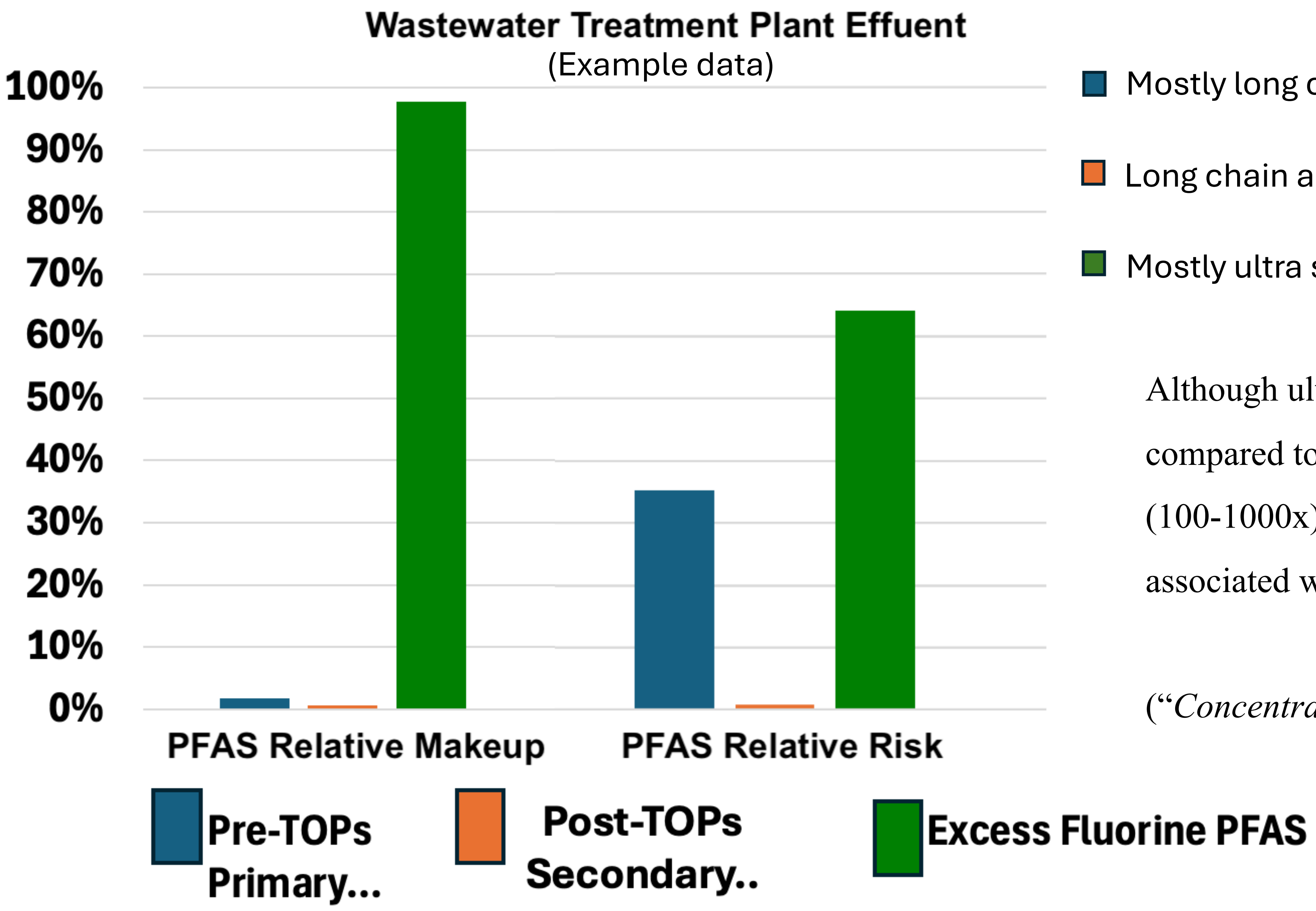
<u>Total PFAS' Risk =</u>

Primary Terminal PFAS' Risk +
Secondary Terminal PFASs Risk +
Excess Fluorine PFAS' Risk

Or

Pre-TOPs + Post-TOPs + TOFs

Possible composition:



- Mostly long chain PFAS
- Long chain and some short chain PFAS
- Mostly ultra short chain PFAS

Although ultra short PFAS are less toxic compared to long and short PFAS (100-1000x), high concentrations is associated with higher risk

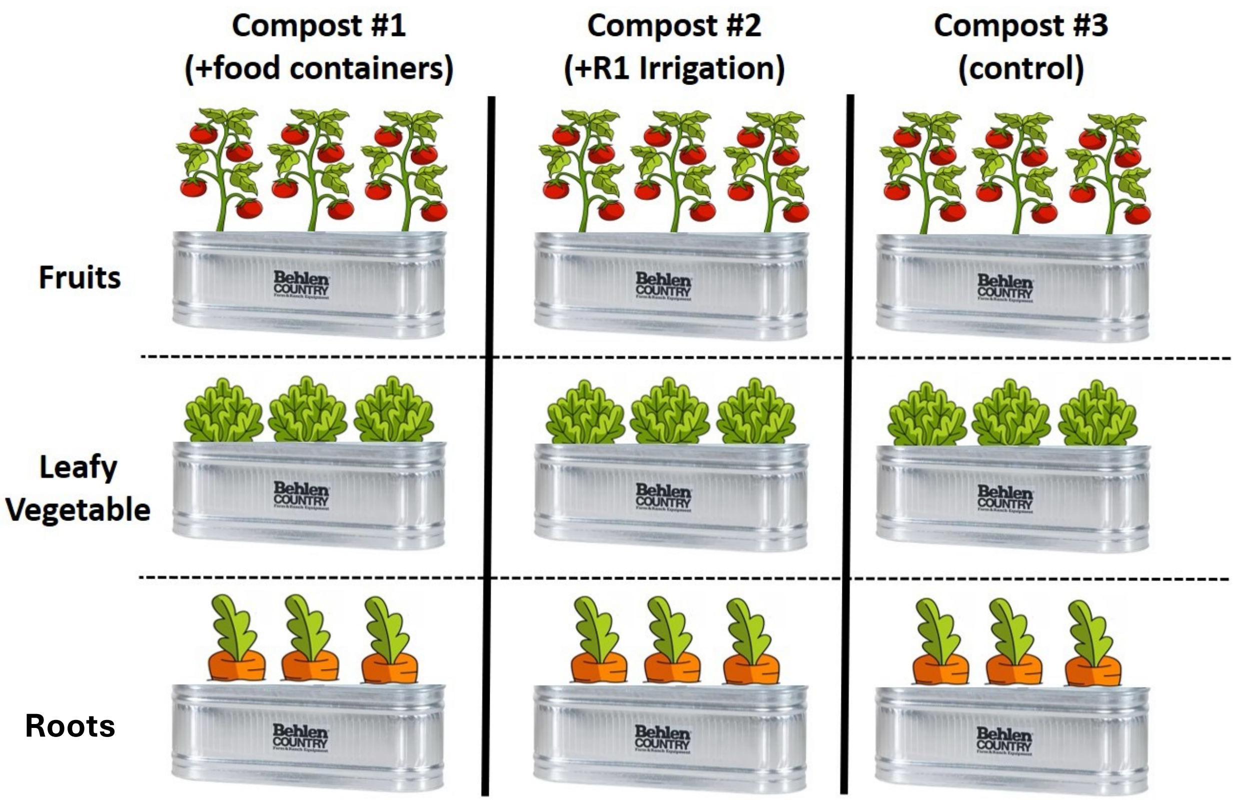
("*Concentration makes the poison*").

Reference: https://health.hawaii.gov/heer/files/2024/11/Hawaii-PFAS-Study-HIDOH-Nov-2024-rev-Nov-15-2024.pdf

Study Methodology:

The baseline PFAS levels will be determined:

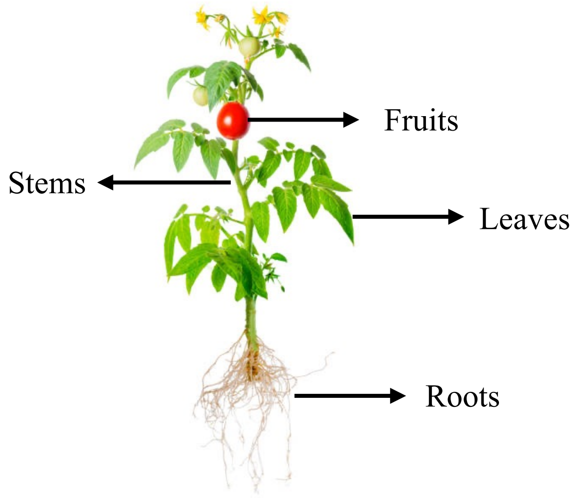
- ❖ Food waste
- ❖ **Service wares**
- ❖ Municipal water (little or no PFAS)
- ❖ **R1 wastewater**
- ❖ Compost #1
- ❖ Compost #2
- ❖ Compost #3



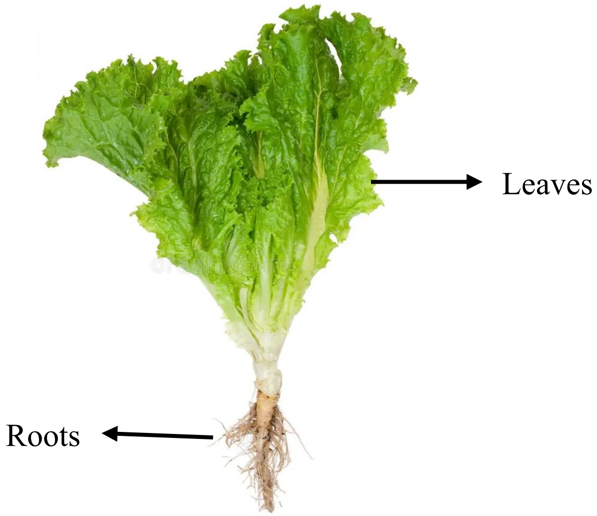
Compost Preparation:	Green Waste + Food Waste **+ Service Ware**	Green Waste + Food Waste	Green Waste + Food Waste
Preparation and Plant Irrigation:	Municipal Water	**R1 Wastewater**	Municipal Water

Plant tissues to be tested:

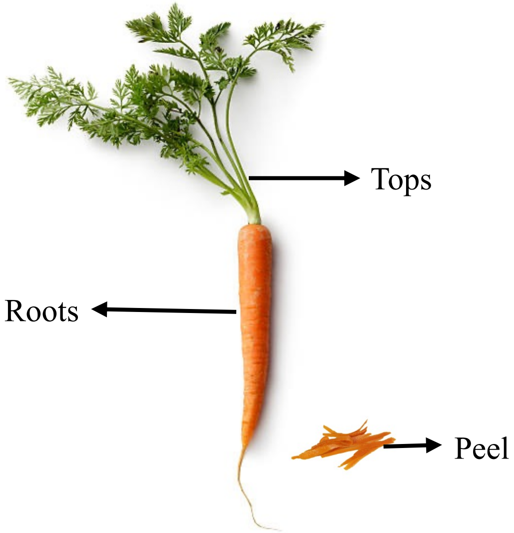
Which PFAS are accumulating, and where?



Fruits
(*tomatoes*)



Leafy vegetables
(*Kale*)



Root vegetable
(*carrots*)

Future Directions:

Results will help us make decisions and legislation

R1 water and/or service ware compost

Hypotheses

Safe for all consumable crops

Safe for some crops but not all

e.g., low/safe level or no PFAS uptake in tomatoes and lettuce but unsafe levels in carrots

Not safe for any consumable crops

i.e., perhaps safe for non-consumable crops such as hemp

Anticipated to finish this study by next year