The Hebrew University of Jerusalem

Organic contaminants in fresh produce irrigated with treated wastewater: Human exposure and health concerns

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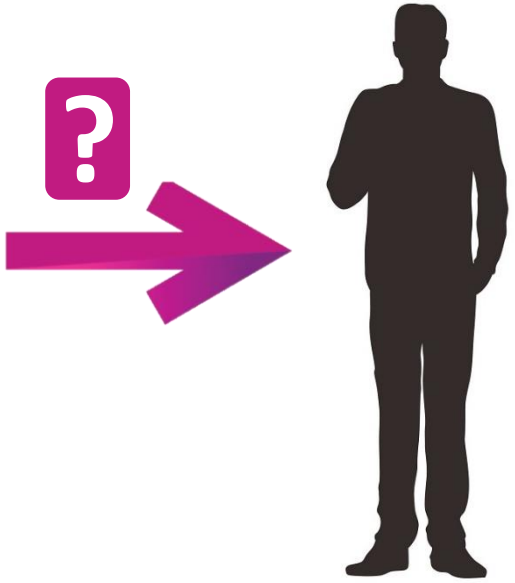
Tali Sinai, Tamar Berman, Rita Dichtiar,
Lital Keinan-Boker, Jorge Tarchitzky,
Vered Mordehay, Yehoshua Maor, Orly Manor,
and Benny Chefetz



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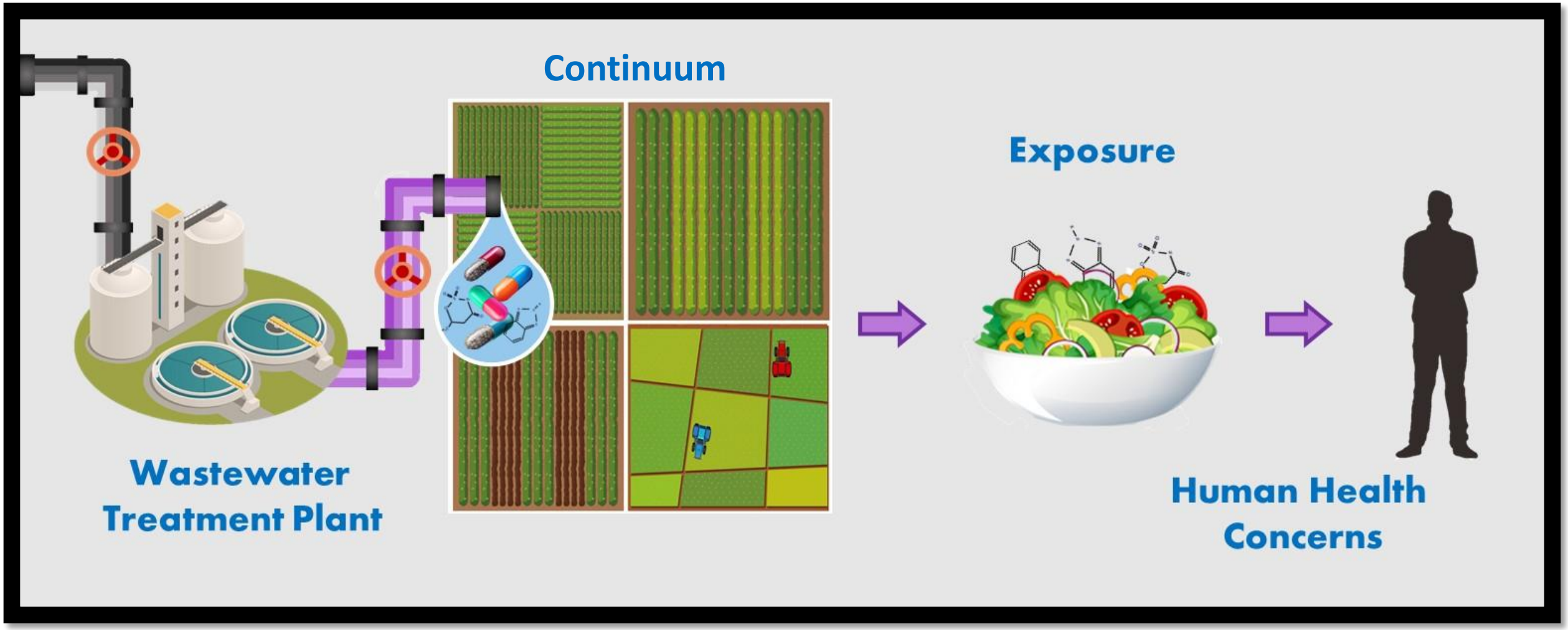
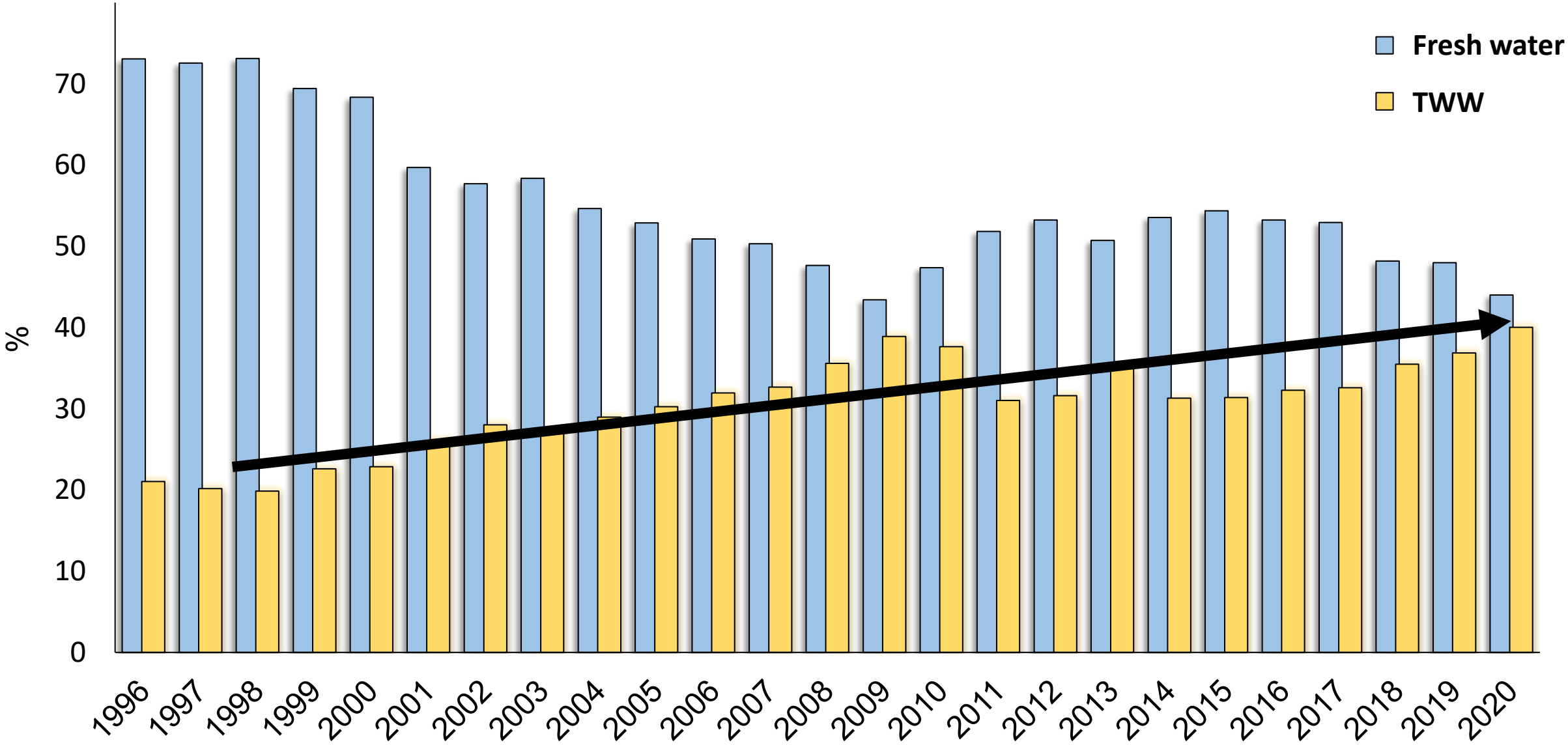
The Hebrew University of Jerusalem

Motivation



Water (reclaimed wastewater) → soil (farmland) → plant (*in planta* processes) → human (consumer)

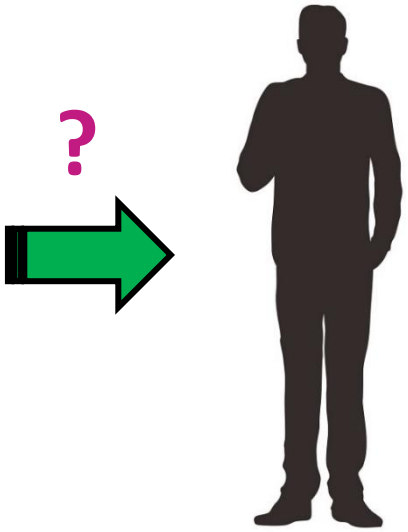
Treated wastewater usage in Israel



Central Bureau of Statistics; Israel

Objectives

To estimate human exposure to contaminants of emerging concern (CECs) based on the consumption of produce irrigated with treated wastewater and to assess human health concerns.



Exposure assessment

CECs in produce crops

X

Human consumption

CECs in irrigated crops at the field: current state of knowledge

Riemenschneider et al. (2016)
28 pharmaceuticals;
7 crops: Potato, carrot, leafy greens, tomato, pepper eggplant, and zucchini
Collected from **1 field (per crop)**

Liu et al. (2020)
12 pharmaceuticals;
4 crops: Eggplant, wheat, long bean and cucumber
Collected from **13 fields**

de Santiago-Martín et al. (2020)
4 pharmaceuticals;
1 crop: Maize
Collected from **5 locations**

Tadić et al. (2021)
10 antibiotics;
4 crops: Lettuce, tomato, beans, and cauliflower
Only crops were collected from **6 fields**

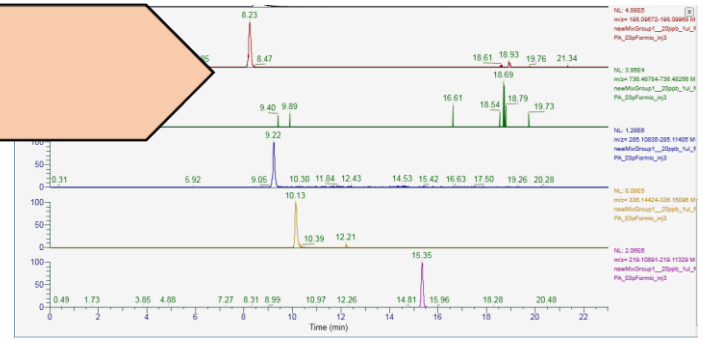
Camacho-Arévalo et al. (2021)
5 sulfonamides;
1 crop: Tomato
Collected from **2 greenhouses**

Exposure and risk assessment

Method: National survey of crops irrigated with treated wastewater

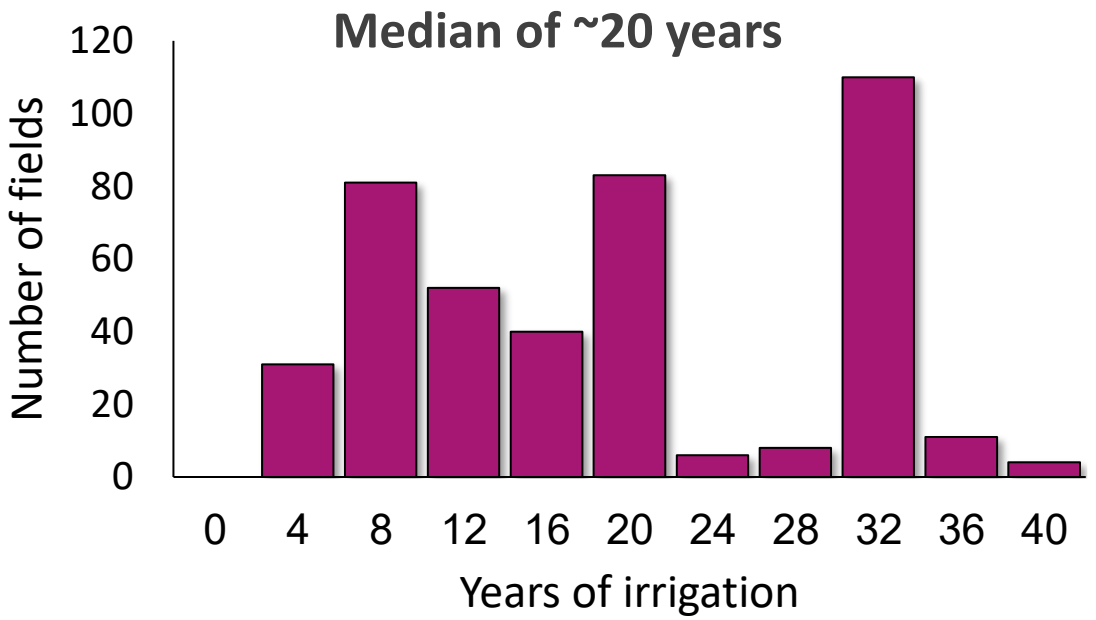
Crops selection → **number of samples** → **Sampling method** → **Actual sampling**

Method development



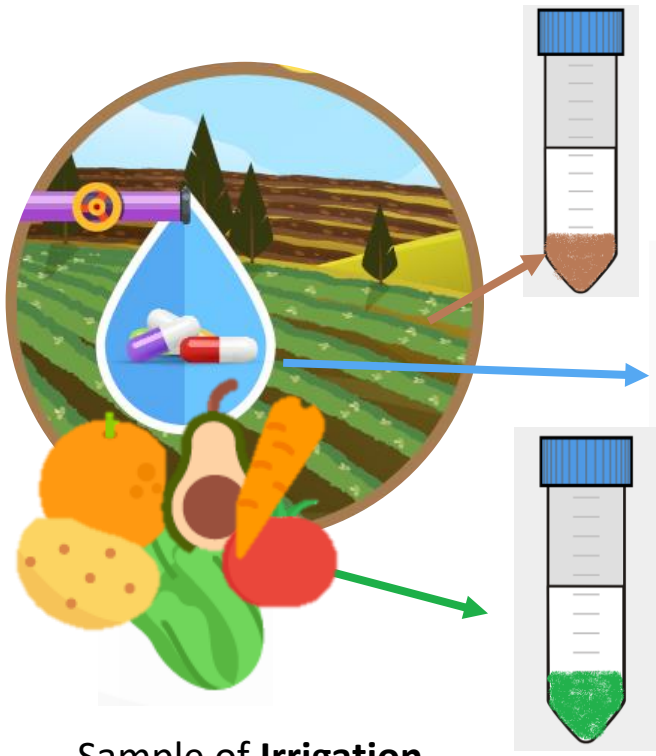
Sampling overview

- **469 fields (2017-2019)**
- 11 crops
- Treated wastewater irrigation
- Irrigation water, Soil, and **Crop** samples
- 65 contaminants

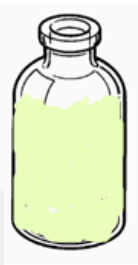


Irrigation water, Soil, and Crop

Sample preparation method



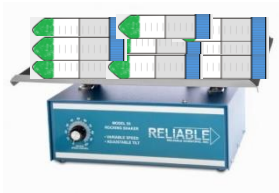
Sample of **Irrigation water, soil and plant**



ISTDs addition

Water samples

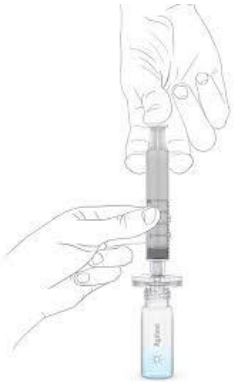
Soil/plant samples



Extraction method

Drying and reconstitution

Clean up



MS Analysis

Extraction and analytical method per matrix:

Mean analytes recoveries >90%;

Mean R^2 of calibration curves >0.95

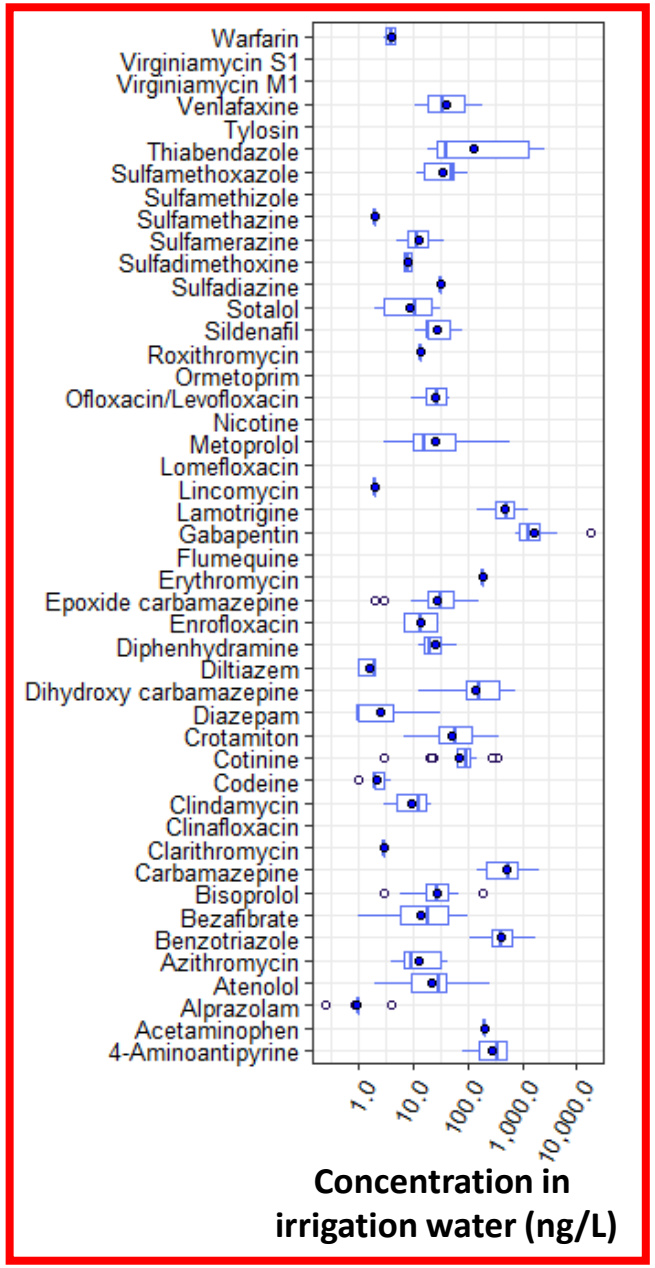
Methodology:

Conc. < LOD → **0**

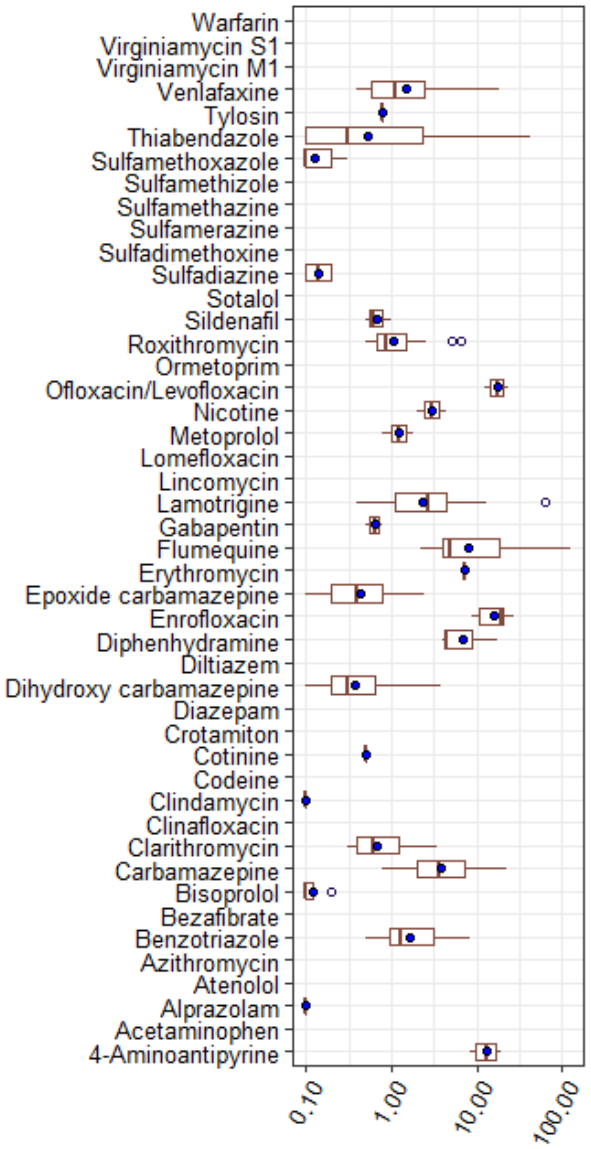
LOD ≤ Conc. < LOQ → **LOQ/2**

Conc. ≥ LOQ → **Conc.**

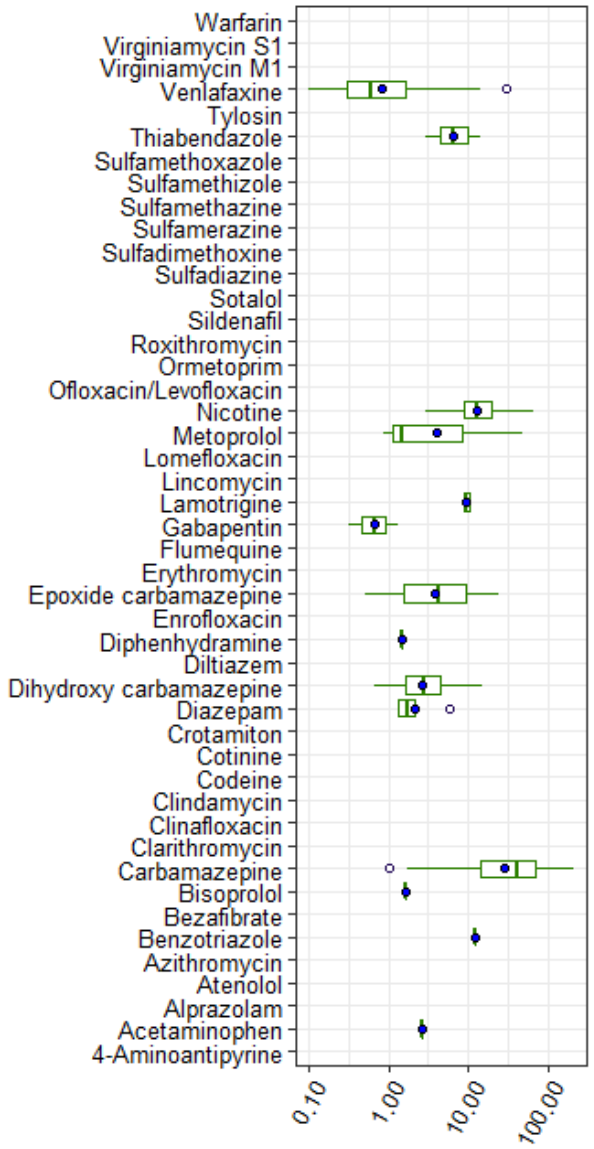
CECs in irrigation water, soils, and avocado plant (conc. ≥LOQ)



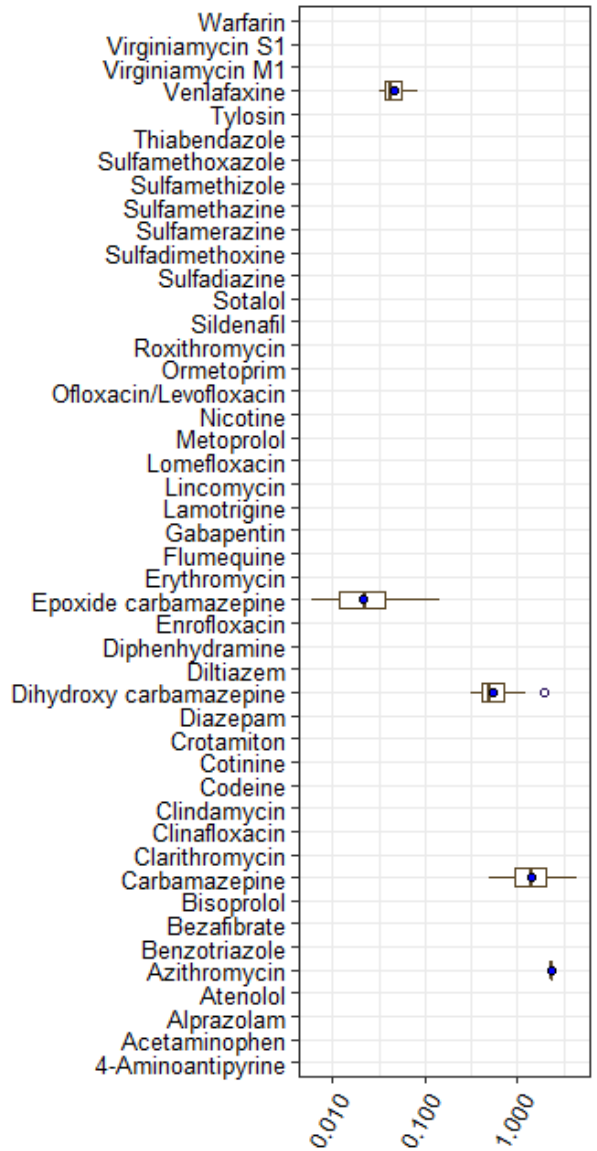
Concentration in irrigation water (ng/L)



Concentration in soils (ng/g)

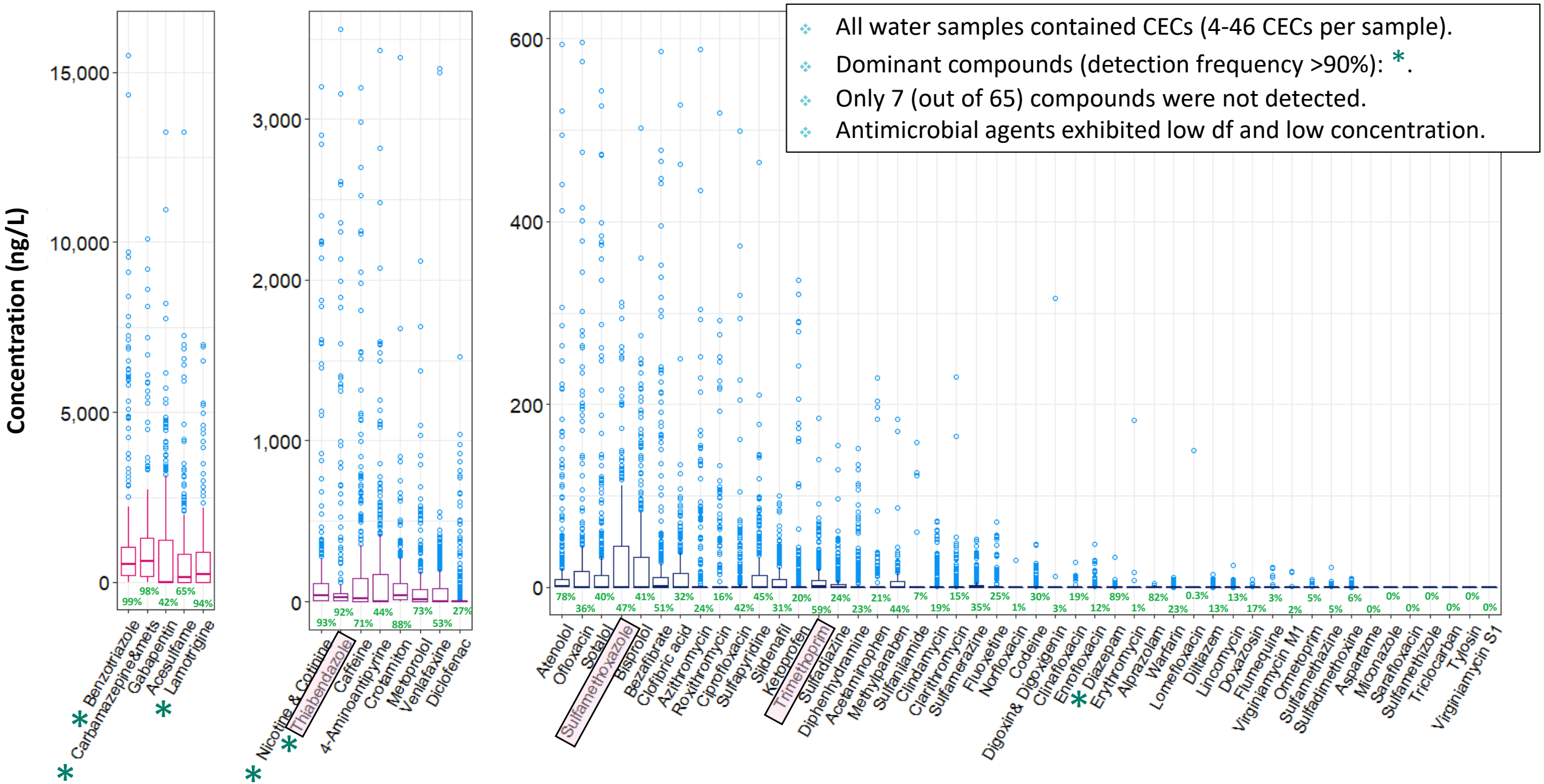


Concentration in leaves (ng/g)



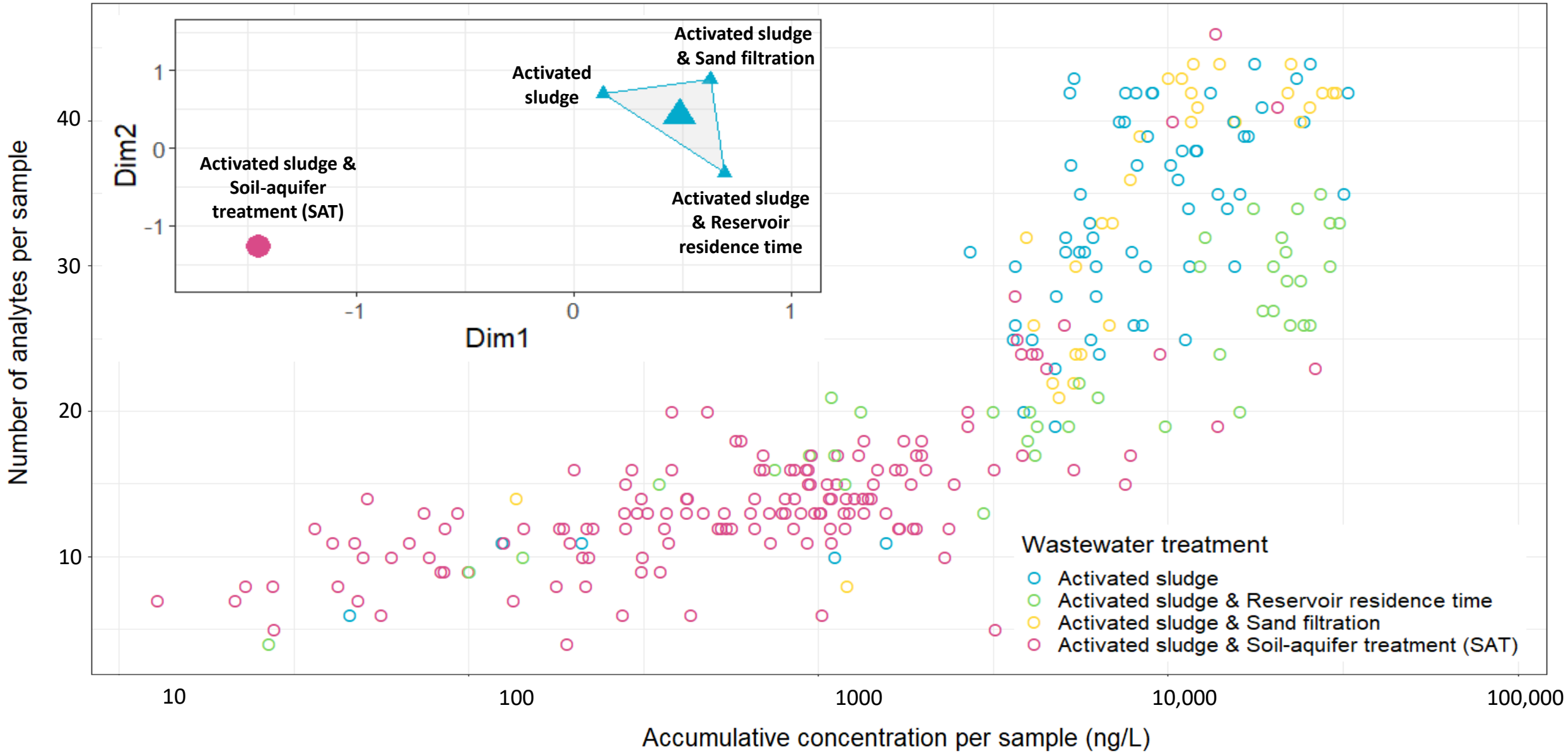
Concentration in fruit (ng/g)

CECs in irrigation water (treated wastewater)

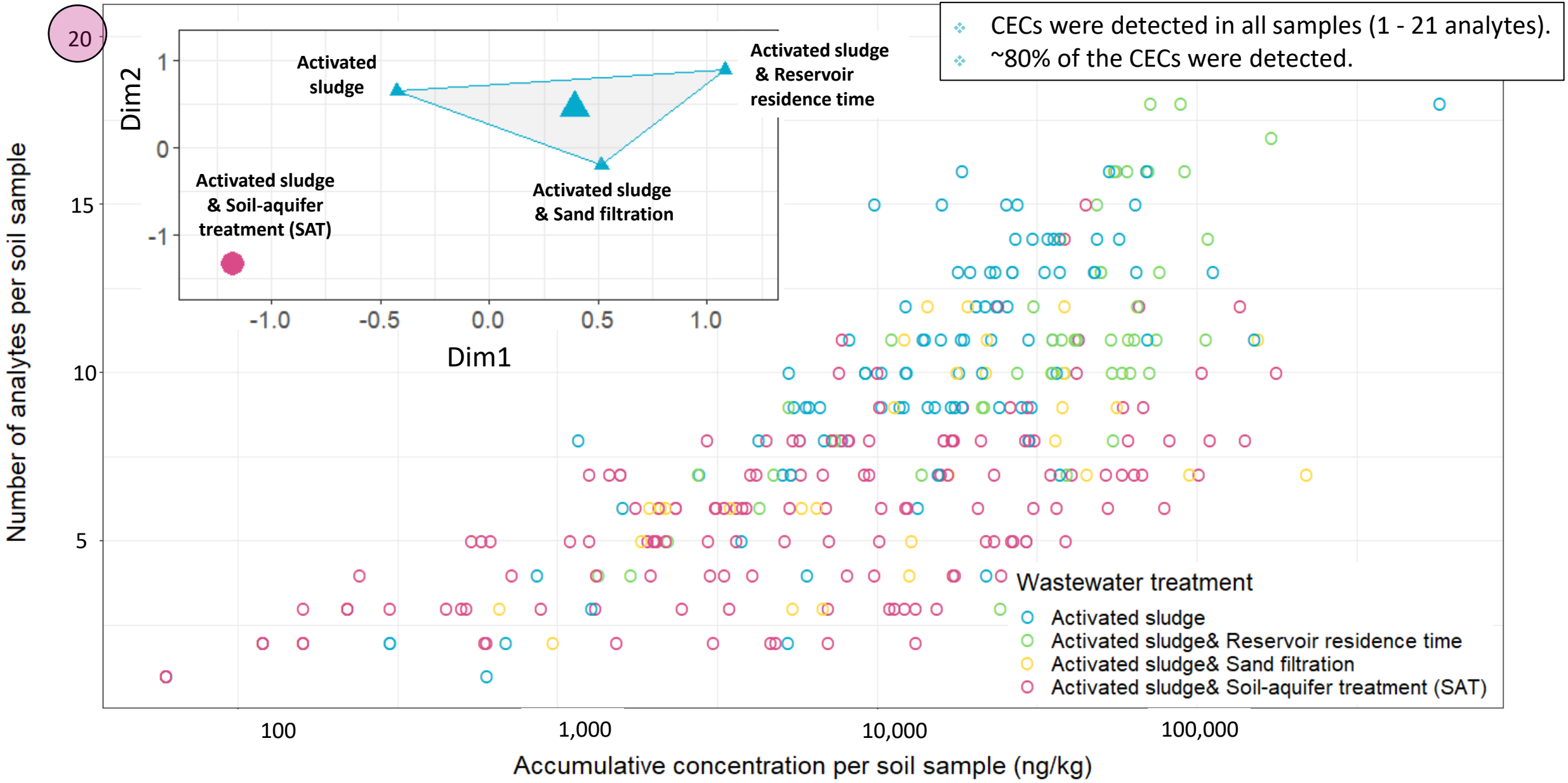


- All water samples contained CECs (4-46 CECs per sample).
- Dominant compounds (detection frequency >90%): *.
- Only 7 (out of 65) compounds were not detected.
- Antimicrobial agents exhibited low df and low concentration.

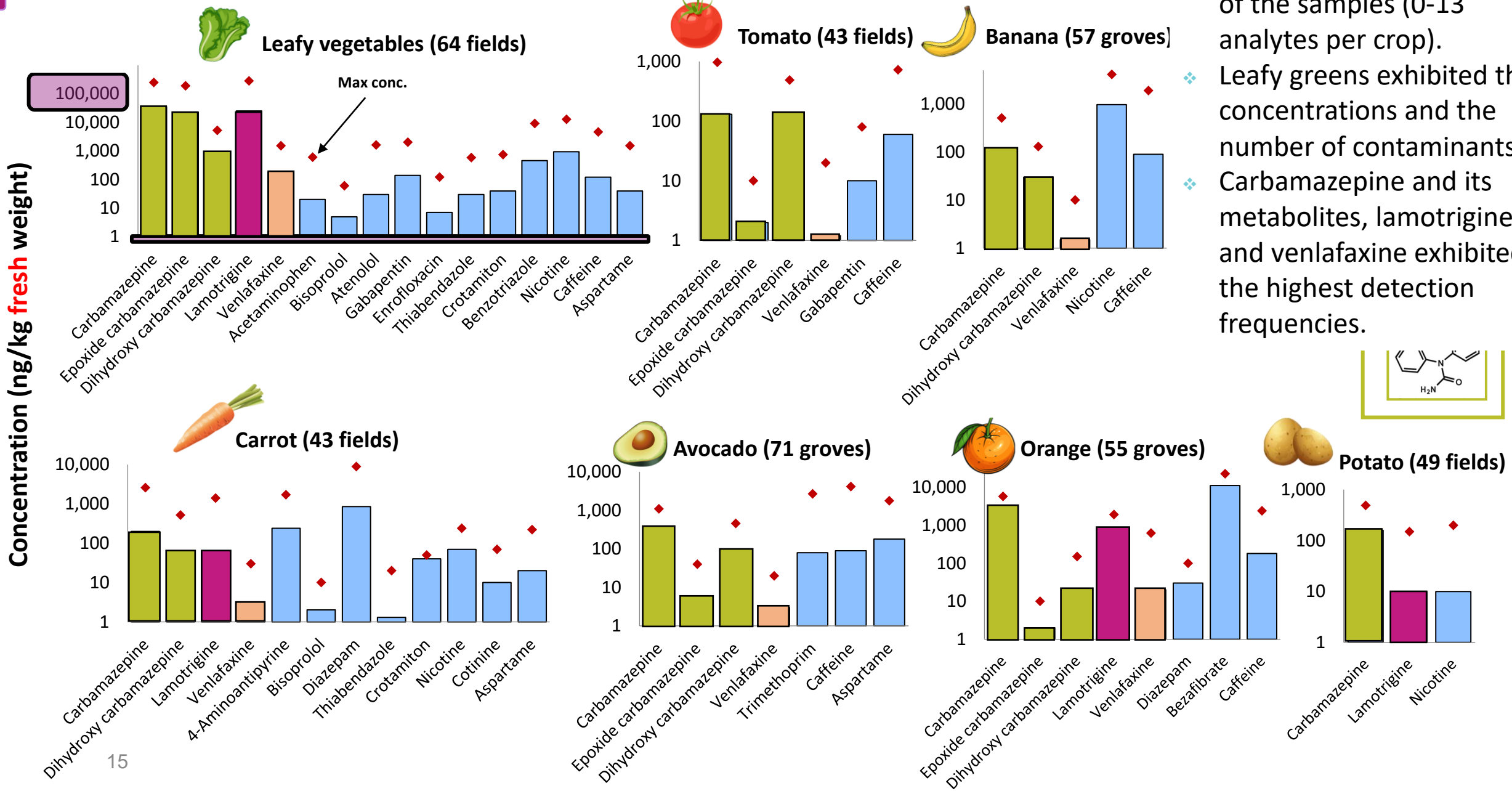
Contaminants of emerging concern (CECs) in irrigation water



CECs in irrigated soils: Effect of wastewater treatment

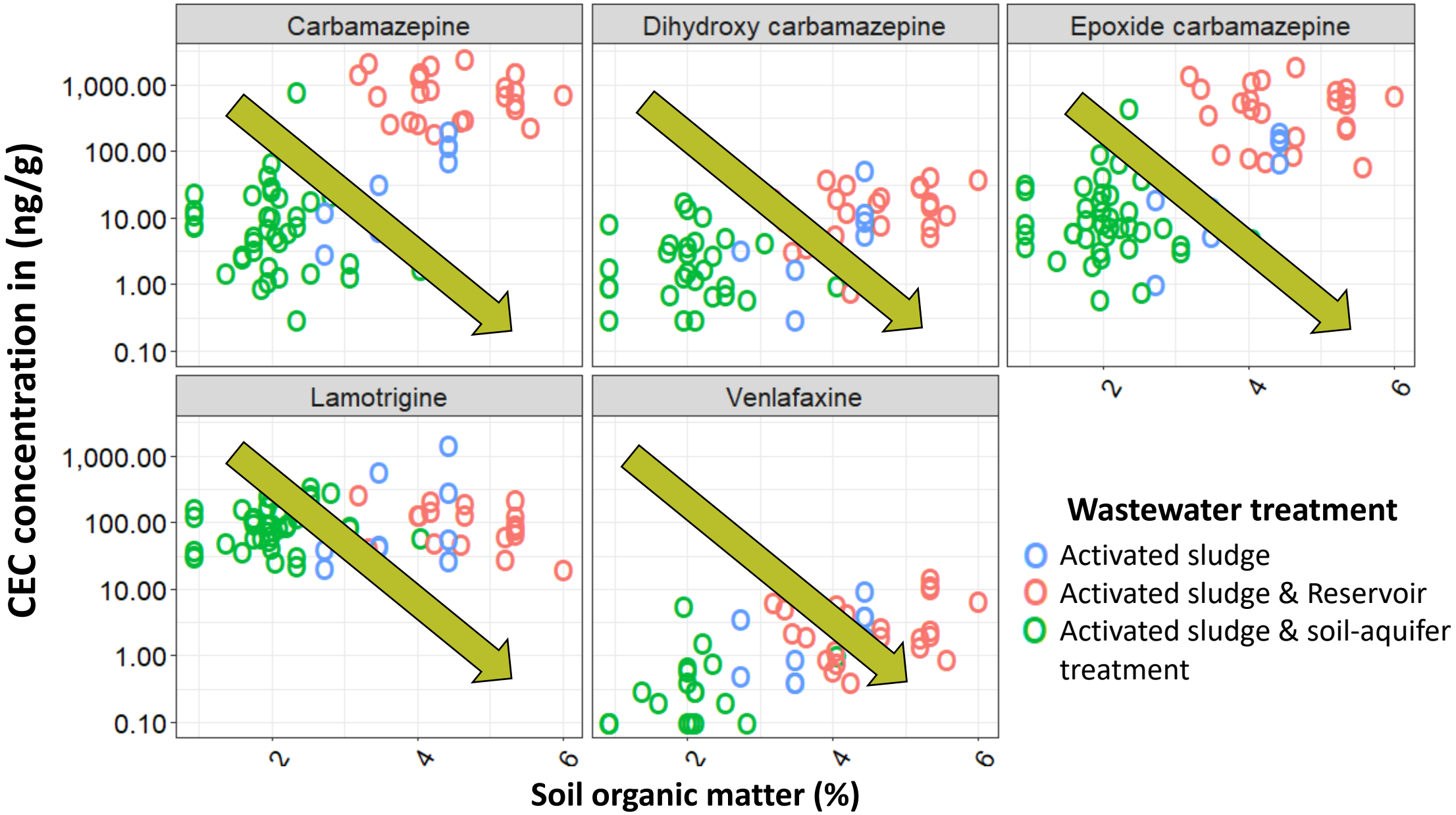


CECs in selected produce crops



- CECs were detected in 98% of the samples (0-13 analytes per crop).
- Leafy greens exhibited the concentrations and the number of contaminants.
- Carbamazepine and its metabolites, lamotrigine, and venlafaxine exhibited the highest detection frequencies.

CECs concentration in Leafy vegetables: Effect of soil organic matter (?)



Exposure assessment

CECs in produce crops

X

Human consumption

Environmental Science & Technology

Article

pubs.acs.org/est

Human Exposure to Wastewater-Derived Pharmaceuticals in Fresh Produce: A Randomized Controlled Trial Focusing on Carbamazepine

Ora Paltiel,[*,†,‡,§] Ganna Fedorova,[§,∥] Galit Tadmor,[†,§,∥] Geffen Kleinstern,[†,§] Yehoshua Maor,[§] and Benny Chefetz[§,∥]

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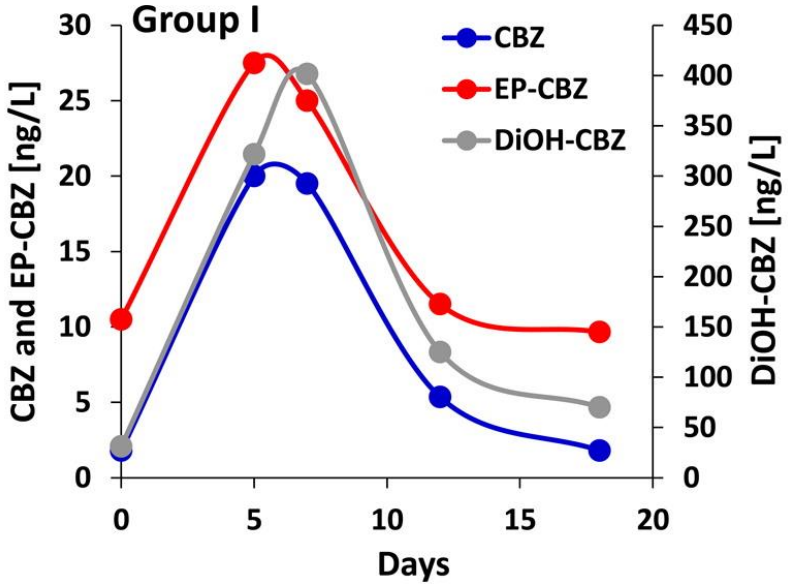
Proof of Concept Study



Paltiel et al., 2016

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Environment International

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Involuntary human exposure to carbamazepine: A cross-sectional study of correlates across the lifespan and dietary spectrum

Michael Schapira[a], Orly Manor[a], Naama Golan[b], Dorit Kalo[c], Vered Mordehay[b], Noam Kirshenbaum[b], Rebecca Goldsmith[a,d], Benny Chefetz[b,*,1], Ora Paltiel[a,*,1]

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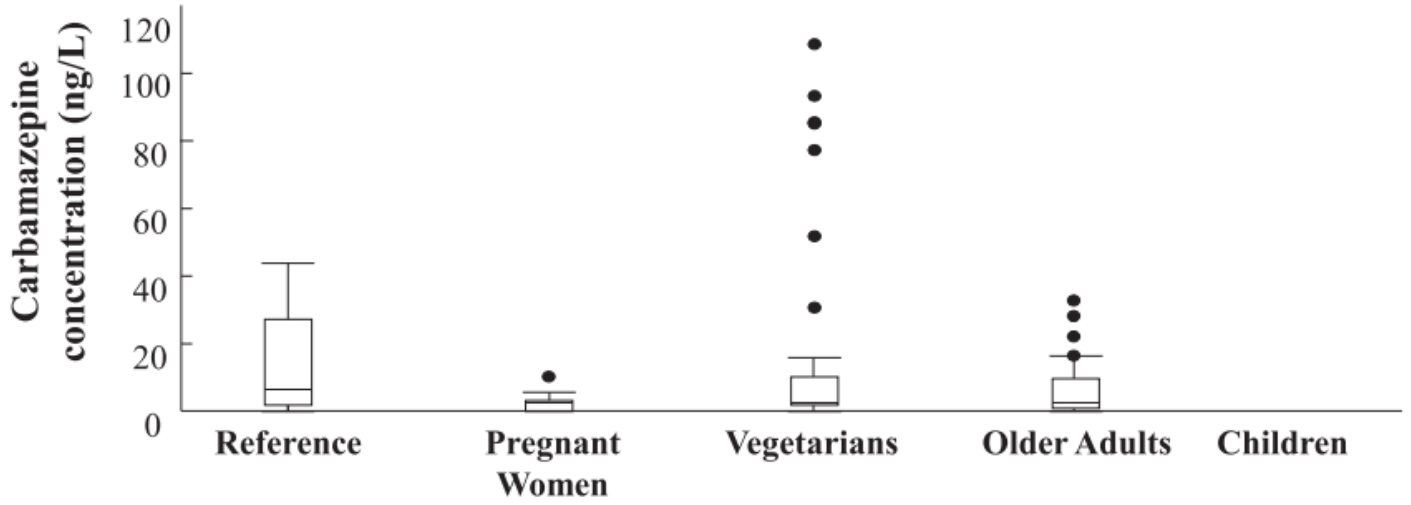


Schapira et al., 2020

Produce corps consumption; Tali Sinai, Israel Ministry of Health

Rav Mabat adults survey 2014-2016; age 18-64; n = 2808 (g/person/day)

Crop	Mean ± SD	Median	95th percentile	Percentage of total produce consumption (%)
Tomato	68 ± 94	41	235	19 (19.1%)
Potato	40 ± 81	0	200	30 (11.2%)
Cucumber	37 ± 69	11	150	41 (10.5%)
Apple	29 ± 77	0	176	49 (8.2%)
Leafy vegetables	22 ± 44	2	104	55 (6.1%)
Pepper	16 ± 49	0	87	60 (4.6%)
Onion	14 ± 26	0	64	64 (4.0%)
Banana	14 ± 47	0	128	68 (3.8%)
Carrot	13 ± 35			71 (3.6%)
Orange	13 ± 62			75 (3.6%)
Grapes	11 ± 65			78 (3.1%)
Peach	10 ± 42			81(2.7%)
Watermelon	9 ± 47			83 (2.6%)
Tangerine	6 ± 32			87 (1.7%)
Zucchini	6 ± 34			88 (1.7%)
Eggplant	6 ± 28			90 (1.4%)
Mango	5 ± 40	0	0	91 (1.1%)
Pear	4 ± 23	0	0	92 (1.1%)
Melon	4 ± 34	0	0	93 (1.1%)
Avocado	4 ± 17	0	30	94 (1.1%)
Lemon	4 ± 22	0	15.1	100 (6.0%)
Others (15 crops)	21	-	-	

Produce consumption:

ISRAEL: 356 g/person/day

Europe: 314 g/person/day

US: 330 g/person/day

76% of the produce consumption

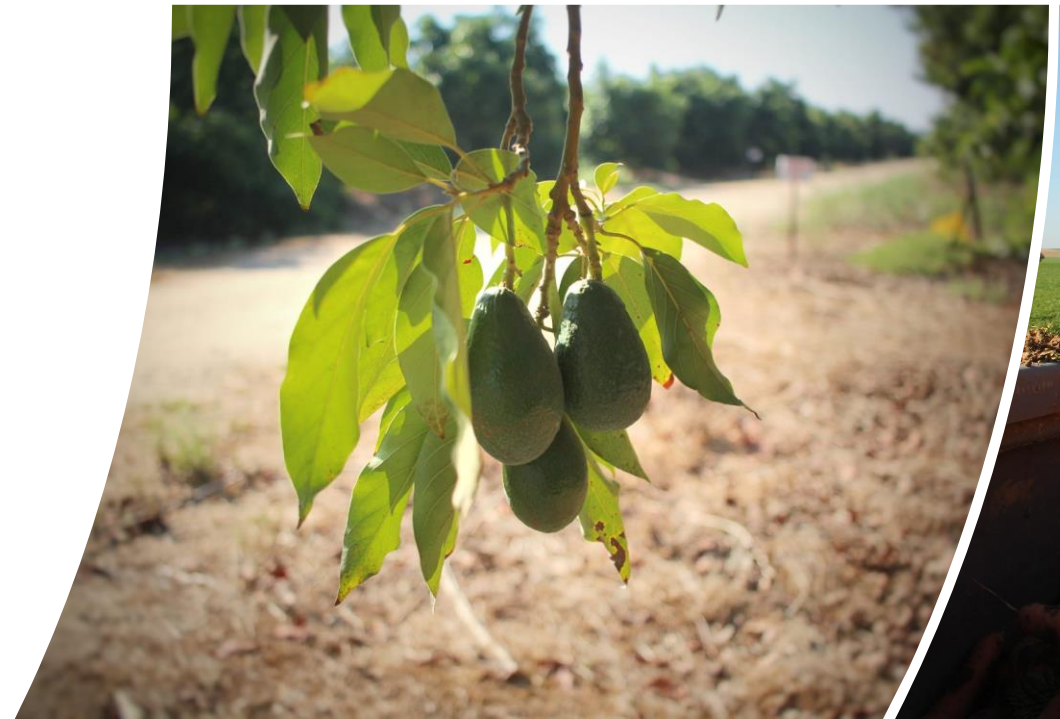
Exposure assessment

CECs in produce crops

X

Human consumption

Human exposure



Exposure assessment approach

Conc. in edible crops × human consumption

Scenarios

Mean-exposure	High-exposure	Extreme-exposure
Mean CEC concentration in produce × **Mean** produce consumption	**Maximum** concentration × **Mean** consumption	**Maximum** concentration × 95th **percentile** consumption

Human estimated exposure to CECs (ng CEC/adult person/day)

Group	Compound	Mean-level	High-level	Extreme-level	Extreme exposure			
		General population n=2808			Males n=1341	Females n=1467	Vegetarians n=126	Arabs n=491
Analgesics	4-Aminoantipyrine	3	20	110	110	120	230	70
	Acetaminophen	1	10	60	60	60	70	110
Antiarrhythmics	Atenolol	1	30	160	170	160	190	280
	Bisoprolol	0	1	7	7	7	8	10
	Metoprolol	0	1				8	10
	Sotalol	0					60	80
Anticonvulsants	Carbamazepine	870					31,300	46,100
	Dihydroxy-carbamazepine	50					990	1,200
	Epoxide-carbamazepine	510					22,700	33,600
	Gabapentin	4					270	390
	Lamotrigine	570					33,700	50,200
Antidepressants	Diazepam	10					1,200	400
	Venlafaxine	5					210	410
Antimicrobials	Enrofloxacin	0					10	20
	Sulfamethoxazole	20					200	70
	Thiabendazole	1	10	60	60	60	70	100
	Trimethoprim	0	10	80	60	80	130	40
Antiparasitic	Crotamiton	1	20	80	80	80	100	130
Corrosion inhibitor	Benzotriazole	10	200	930	940	910	1,100	1,600
Hypolipidemics	Bezafibrate	160	310	2,500	2,600	2,400	520	3,700
	Warfarin	-	1	8	7	10	10	3
Psychoactives	Caffeine	20	250	1,400	1,500	1,300	1,200	1,900
	Cotinine	1	6	30	50	10	20	50
	Nicotine	40	380	2,100	2,200	2,100	2,100	3,000
Sweetener	Aspartame	2	40	220	210	220	300	300
	Sum	**2,300**	**17,700**	**85,700**	**87,000**	**83,700**	**96,700**	**143,800**

Mean conc. × Mean consumption

Max conc. × Mean consumption

Max conc. × 95th percentile consumption

0.14 mg/person/day

Exposure

⇩

Risk?

Acceptable daily intake (ADI) and threshold of toxicological concern (TTC)

Group	Compound	**Lowest ADI** (ng for a 70 kg person/day)	**TTC class**	**TTC** (ng for a 70 kg person/day)
Analgesics	4-Aminoantipyrine	-	Genotoxic	10,500
	Acetaminophen	220,000	Genotoxic	10,500
Antiarrhythmics	Atenolol	28,000	1	2,100,000
	Bisoprolol	-	1	2,100,000
	Metoprolol	8,400	1	2,100,000
	Sotalol	-	Genotoxic	10,500
Anticonvulsants	**Carbamazepine**	**24,000**	**3**	**105,000**
	Dihydroxy carbamazepine	23,000,000	3	105,000
	Epoxide carbamazepine	**200,000**	**Genotoxic**	**10,500**
	Gabapentin	-	3	105,000
	Lamotrigine	**830,000**	**Genotoxic**	**10,500**
Antidepressants	Diazepam	11,000	3	105,000
	Venlafaxine	-	1	2,100,000
Antimicrobials	Enrofloxacin	21,000	3	105,000
	Sulfamethoxazole	27,000	Genotoxic	10,500
	Thiabendazole	70,000	3	105,000
	Trimethoprim	660,000	Genotoxic	10,500
Antiparasitic	Crotamiton	-	1	2,100,000
Corrosion inhibitor	Benzotriazole	-	3	105,000

$$\text{Hazard quotient (HQ)} = \frac{\text{Exposure level (current study)}}{\text{ADI or TTC (literature data)}}$$

Scenarios

Mean exposure

Mean concentration
in produce
×
Mean produce consumption

High exposure

Maximum concentration
×
Mean consumption

Extreme exposure

Maximum concentration
×
95th **percentile** consumption

Hazard quotients for Extreme exposure level

$$HQ = \frac{\text{Exposure level}}{\text{ADI/TTC}}$$

Group	Compound	General population		Vegetarians		Arabs	
		ADI based	TTC based	ADI based	TTC based	ADI based	TTC based
Analgesics	4-Aminoantipyrine	NA	0.01	NA	0.02	NA	0.01
	Acetaminophen	0	0.01	0	0.01	0	0.01
Antiarrhythmics	Atenolol	0.01	0	0.01	0	0.01	0
	Bisoprolol	NA	0	NA	0	NA	0
	Sotalol	NA	0	NA	0.01	NA	0.01
Anticonvulsants	**Carbamazepine**	**1.13**	0.26	**1.3**	0.3	**1.92**	0.44
	Dihydroxy-carbamazepine	0	0.01	0	0.01	0	0.01
	Epoxide-carbamazepine	0.10	**1.86**	0.11	**2.16**	0.17	**3.20**
	Gabapentin	NA	0	NA	0	NA	0
	Lamotrigine	0.04	**2.77**	0.04	**3.21**	0.06	**4.78**
Antidepressants	Diazepam	0.06	0.01	0.11	0.01	0.04	0
	Venlafaxine	NA	0	NA	0	NA	0
Antimicrobials	Enrofloxacin	0	0	0	0	0	0
	Sulfamethoxazole	0	0.02	0	0.02	0	0.01
	Thiabendazole	0	0	0	0	0	0
	Trimethoprim	0	0.01	0	0.01	0	0
Antiparasitic	Crotamiton	NA	0	NA	0	NA	0
Corrosion inhibitor	Benzotriazole	NA	0.01	NA	0.01	NA	0.02

Limitations (?)

Underestimation (Exposure and Risk)

- Only 76% of the edible produce.
- Not all contaminants and metabolites.
- Health effect of the mixture is not fully evaluated.
- A 24-hour dietary recall is not necessarily representative of the overall diet.

Main findings and conclusions

- Leafy greens exhibited the highest number and concentration of contaminants → main source of human exposure (mainly affected by the water quality).
- For the mean and high exposure scenarios → no human health concerns were predicted.
- For the extreme exposure scenario, HQs for lamotrigine, carbamazepine, and epoxide-CBZ were >1, indicating possible human health risks.
- By considering freshwater and treated wastewater irrigation, HQs for all contaminants were <1 indicating no human health concerns.

What's next:
Regulation? Treatment? Agricultural practices?

Acknowledgments

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Pharmaceuticals in edible crops irrigated with reclaimed wastewater: Evidence from a large survey in Israel

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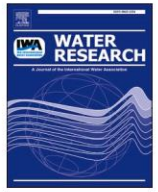

Wastewater-derived organic contaminants in fresh produce: Dietary exposure and human health concerns

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Fate of contaminants of emerging concern in the reclaimed wastewater-soil-plant continuum

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