Collection of berries for Human Health Risk Assessments grown in PAH or PCB contaminated soil: a worthwhile effort or a desktop exercise?

Prepared by: Faye d'Eon-Eggertson, Cher LaCoste, Phil Zylka

Abstract

The consumption of berries grown on contaminated soils is continually identified in conceptual exposure models as a potential exposure route for human and ecological receptors. Berries can be challenging to sample due to time constraints of growing seasons, accessibility of sufficient sample size, and cost. Organic pollutants such as Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) can present significant human health risks, but there is a paucity of guidance relating to their uptake into berries. This paper reviews the literature on bioavailability and translocation of PAHs and PCBs from the soil into plant tissues, including chemical properties and physiological processes, and mechanisms of contaminant control in the rhizosphere and within the plant. The literature indicates that there are multiple barriers to PAH and PCB entry into plants, as well as several mechanisms of breakdown, sequestration and expulsion. Several studies have found an absence of correlation between soil and berry contamination levels, and others have concluded that PCBs and PAHs remain primarily in the soil and that contamination of plants is likely from airborne exposure. There are large knowledge gaps on uptake mechanisms, routes of exposure, and between-species variability in organic pollutant uptake into berries. We conduct an assessment of the human health risk from berry consumption due to the uptake of contaminants from the soil based on reference values of hydrophobicity, bioconcentration factors, human consumption rates, and Toxicological Reference Values. The weight of evidence suggests that the soil-to-root pathway for PAH and PCB uptake in berries should not be a significant pathway for human health risk assessments unless soil concentrations are very high, consumption of berries is high, or the chance of aerial soil particles is high.

Literature Review: Barriers to Uptake of PAHs and PCBs into berries

A detailed literature review and data compilation exercise was undertaken to identify the likelihood of PAHs and PCBs translocating from the soil into aboveground edible plant tissue. A summary of key information is provided below.

Transfer of contaminants into aboveground plant tissue

- ⇒ Transportation of organic chemicals into the leaf or fruiting bodies requires passive diffusion from xylem; less likely for hydrophobic molecules (such as PCBs & PAHs) *(Collins et al. 2006)*
- ⇒ Natural chelators modify, sequester and isolate potentially harmful chemicals in non-essential tissues (*i.e.*, not the fruiting bodies) *(Pilon-Smits 2005)*
- ⇒ Additional enzymatic mechanisms are present to either break down pollutants or modify them to be more readily absorbed into non-essential tissues *(Pilon-Smits 2005)*
- ⇒ Some studies found higher levels of contamination in non-reproductive tissues (roots, stem, leaves) than in reproductive tissues *(Fismes et al. 2002, Hoylman & Walton 1994)*
- ⇒ Several studies found no correlation between soil contamination and PCBs or PAHs measured in the fruit *(Wieczorek et al. 2010, Samsoe-Petersen et al. 2002)*

Transfer of contaminants into root tissue

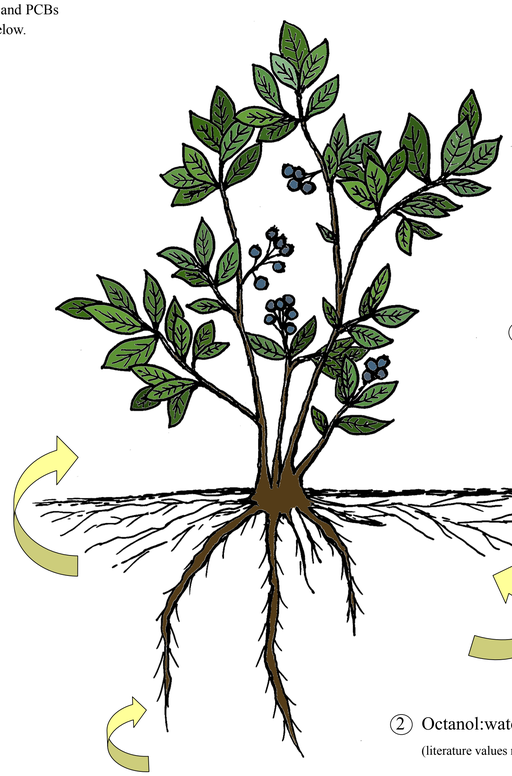
- ⇒ No active transport mechanism; uptake only occurs through passive diffusion *(Pilon-Smits 2005)*
- ⇒ Root structures composed of lipid-based barriers; hydrophobic molecules (such as PCBs & PAHs) bind to the barriers, do not easily diffuse out of them into xylem unless root is highly saturated with PCBs/PAHs *(Pilon-Smits 2005, Kacálková & Tlustoš 2011)*

Contaminants in the soil and rhizosphere

- ⇒ High bonding affinity to the soil matrix *(Maa et al. 2010, Suter 1997)*
- ⇒ In one study, >86% of PAHs remained in the soil *(Hoylman & Walton 1994)*
- ⇒ Phytostimulation promotes microbe activity in the rhizosphere; microbes break down organic pollutants *(Mueller & Shann 2006, Collins et al. 2006)*

Key challenges & data gaps

- ⇒ Lack of bioconcentration factors specifically for berries related to PAHs or PCBs
- ⇒ PAH and PCB contamination of berries may not be due to uptake pathway (*i.e.*, contamination of fruit may be due to airborne sources, volatization from soil, or incidental soil contact with exposed fruit) *(Collins & Finnegan 2010, Samsoe-Petersen et al. 2002, Tao et al. 2004)*
- ⇒ Several studies have suggested that airborne contamination is a larger contributor to PAH and PCB contamination in plants than soil-based contamination *(Pier et al. 2002, Barcan et al. 2000, Carmago & Toledo 2003)*
- ⇒ Large variability between plant species and between PAH and PCB congeners



⑥ Compare to Toxicological Reference Values *(Health Canada 2010)* — low uncertainty

⑤ Human consumption *(EPA 2011)*

*Exposure = Pr * consumption* — moderate uncertainty

④ Contaminant concentration in above ground plant parts (*Pr*) *(EPA 2005)*

*Pr = Cs * Br* — moderate uncertainty

③ Plant-soil bioconcentration factor (*Br*) *(EPA 2005)*

log Br = 1.588 - 0.578(log K_{OW}) — moderate uncertainty

② Octanol:water partition coefficient (*log K_{OW}*) — low uncertainty

(literature values related to hydrophobicity of contaminant) *(EPA 2004, 2013)*

① Contaminant concentration in the soil (*Cs*)

(obtained from site measurements) — low uncertainty

L'utilisation des baies cultivées dans des sols contaminés par des HAP et des BPC pour l'évaluation des risques à la santé humaine : un exercice pratique ou seulement théorique?

Résumé

La consommation des baies cultivées dans des sols contaminés est fréquemment identifiée dans les modèles conceptuels comme étant une voie d'exposition potentielle pour les récepteurs humains et écologiques. Les baies peuvent être difficiles à échantillonner à cause des brèves saisons de croissance, des tailles d'échantillon insuffisantes, et le coût d'échantillonnage. Les polluants organiques tels que les hydrocarbures aromatiques polycycliques (HAPs) et les biphényles polychlorés (BPCs) peuvent présenter des risques importants à la santé humaine, mais il y a une pénurie d'informations sur l'absorption des contaminants par les baies. Nous avons réalisé une revue de la littérature scientifique sur la biodisponibilité et la translocation des HAPs et BPCs du sol aux baies, incluant les propriétés chimiques et les processus physiologiques, et les mécanismes de contrôle des contaminants dans la rhizosphère et à l'intérieur de la plante. La littérature scientifique indique qu'il y a plusieurs barrières à l'entrée des HAPs et BPCs dans les plantes, ainsi que plusieurs mécanismes de dégradation, de séquestration et d'expulsion. Plusieurs études ont conclu sur l'absence de corrélation entre les niveaux de contamination dans le sol et dans les baies, et d'autres ont conclu que les HAPs et BPCs restent principalement dans le sol et que la contamination des plantes est probablement la conséquence d'une contamination aérotransportée. Il y a un manque de données sur les mécanismes d'absorption, les voies d'exposition, et la variabilité entre espèces à propos de l'absorption des polluants organiques dans les baies. Nous avons évaluée les risques à la santé humaine associée à la consommation des baies contaminés par l'absorption des contaminants du sol en s'appuyant sur les valeurs de référence d'hydrophobicité, les facteurs de bioconcentration, les taux de consommation humaines, et les valeurs toxicologiques de référence (VTR). Le poids de la preuve suggère que la voie sol-racine pour l'absorption des HAPs et BPCs dans les baies n'est pas une voie importante pour l'évaluation des risques à la santé humaine, sauf dans les cas où les concentrations dans le sol sont très élevées, que le taux de consommation des baies est élevé, ou lorsque le risque d'une exposition aux particules aériennes contaminées est élevée.

Human Health Risk: A Desktop Exercise

In order to evaluate the human health risks from PAHs and PCBs through the soil to plant consumption pathway, a risk matrix was created using known chemical-specific factors, literature uptake rates, and consumption rates.

Example: Incremental Lifetime Cancer Risk for Benzo[a]pyrene

At a berry consumption rate of *0.5$g_{berries}$/kg_{BW}-day*

(equivalent to your presenter eating 1kg of berries in a month)

		Soil concentration ($mg_{B[a]P}/kg_{soil}$)									
log K_{OW}	log Br	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
5.9	-1.82	1.7E-06	3.5E-06	5.2E-06	6.9E-06	8.7E-06	1.0E-05	1.2E-05	1.4E-05	1.6E-05	1.7E-05
6	-1.88	1.5E-06	3.0E-06	4.5E-06	6.1E-06	7.6E-06	9.1E-06	1.1E-05	1.2E-05	1.4E-05	1.5E-05
6.1	-1.94	1.3E-06	2.7E-06	4.0E-06	5.3E-06	6.6E-06	8.0E-06	9.3E-06	1.1E-05	1.2E-05	1.3E-05
6.2	-2.00	1.2E-06	2.3E-06	3.5E-06	4.6E-06	5.8E-06	7.0E-06	8.1E-06	9.3E-06	1.0E-05	1.2E-05
6.3	-2.05	1.0E-06	2.0E-06	3.1E-06	4.1E-06	5.1E-06	6.1E-06	7.1E-06	8.1E-06	9.2E-06	1.0E-05

non-negligible cancer risk

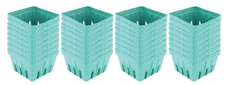
Best estimate of log K_{OW} for Benzo[a]pyrene

Therefore, at this contaminant level and consumption rate, there might be a human health risk and further investigation (including testing berry tissue) would be warranted.

Highest soil concentration sampled at a lightstation

Using the same approach, your presenter would have to eat:

- ⇒ **5.5 kg** of berries/month to experience a non-negligible cancer risk from **Benzo[b]fluoranthene** at the highest soil concentrations observed at a lightstation (1.0 mg/kg)
- ⇒ **22 kg** of berries/month to exceed the Tolerable Daily Intake for **Naphthalene** at the highest soil concentrations observed at a lightstation (4.1 mg/kg)



Conclusions

- ⇒ Weight of evidence suggests that soil-to-berry uptake of PAHs and PCBs generally should not be a significant pathway for risk assessment
- ⇒ Multiple barriers of entry, as well as several mechanisms of breakdown, sequestration, and expulsion
- ⇒ Little to no evidence in the literature that soil uptake is a major contributor to PAH and PCB contamination in plants
- ⇒ Many knowledge gaps
- ⇒ Sampling approach may be warranted where:
  - ⇒ Soil contaminant concentrations are very high
  - ⇒ Berry consumption is very high
  - ⇒ Chance of airborne contamination is high
- ⇒ Risk mitigation measures (*e.g.*, washing produce) could be implemented when airborne contamination is suspected

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