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Impact of Home Preparation and Cooking Methods on Levels of Dioxin and Dioxin-Like Compounds in Foods

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evidence review

Summary

- Human exposure to dioxins and dioxin-like compounds (DLCs) is primarily from ingestion of fish, meat, and dairy products.
- Based on studies where populations were exposed to much higher levels of DLCs than the general population would encounter, some DLCs have been classified as carcinogens/ probable carcinogens. However, uncertainty remains about the possible adverse health effects from low-level chronic exposure to DLCs.
- Although the average Canadian dietary intake of dioxin is within the tolerable level set by the World Health Organization (WHO) and Food and Agriculture Organization of the United Nations, reducing the DLCs level in foods can help reduce risk.
- Household food preparation and cooking methods (skinning, trimming and/or cooking, in addition to the disposal of pan drippings and poaching/boiling liquids) are relatively economical and practical approaches to reduce exposure to DLCs from fish, by an average of 35% at the consumer level.
- Selecting low fat foods (lean cuts of meat, low fat dairy products) and releasing DLCs by cooking or removing the fat portion of the foods during food preparation and cooking can significantly reduce contaminant levels.
- Research on the efficacy of household food preparation to reduce DLC levels in meat and vegetables is limited.
- Both risks and benefits need to be evaluated in order to effectively communicate risks from food contaminants.

Introduction

This document has been prepared for public health professionals who respond to the public about contaminants in food and ways to reduce exposure to those contaminants. This document reviews the literature on the levels of dioxin and dioxin-like compounds (DLCs) in foods and ways to reduce levels using various preparations and cooking methods.

What are DLCs?

Dioxins and dioxin-like compounds (DLCs) are a class of structurally and chemically-related polyhalogenated aromatic hydrocarbons, which include polychlorinated dibenzo p-dioxins (PCDDs or dioxins), polychlorinated dibenzofurans (PCDFs or furans), and polychlorinated biphenyls (PCBs). Normally existing as a mixture of congeners, they are found throughout the environment in soil, water sediments, and air. Seven of the 75 PCDD congeners, 10 of the 135 PCDF congeners and 12 of the 209 PCB congeners are considered to exhibit dioxin-like activity due to chlorine substitution in the 2, 3, 7, or 8 positions.[1,2] The toxicity of DLCs is expressed as toxic equivalent quantities (TEQs), where the most toxic congener, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), is rated as 1.0 and the less toxic congeners as fractions of this using toxic equivalent factors (TEFs).

Exposure to DLCs

As a group of persistent environmental chemicals, dioxins and furans are largely unintentional contaminants released into the environment as by-products of combustion processes, such as waste incineration and burning of coal, wood, and petroleum. PCBs are intentionally produced compounds used in heat transfer fluids and protective coatings because of their high thermal and chemical stability.[3]

The U.S. Environmental Protection Agency (EPA) estimates that 90% of human exposure to DLCs is through the food supply.[1] Most DLCs in foods are associated with the fat portion of foods due to the lipophilicity of these compounds;[1] hence, DLCs bioaccumulate through the food chain. According to the EPA, the greatest contributors to adult dietary dioxin, furan, and PCB exposure from foods are beef, fish, shellfish, and dairy products.[1]

Based on occupational, epidemiological, and animal studies where DLC exposure levels were several times higher than population levels (e.g., 50x for TCDD), some DLCs have been found to be probable or known carcinogens.[4] The International Agency for Research on Cancer has determined that TCDD is a carcinogen, whereas the US Environmental Protection Agency has classified it as a probable carcinogen. EPA has also classified a mixture of chlorodibenzo-p-dioxins (CDDs) with six chlorine atoms (4 of the 6 chlorine atoms at the 2, 3, 7, and 8 positions) as a probable human carcinogen.[4] Both IARC and EPA have classified PCBs as a probable carcinogen.[5] However, these classifications are based on studies involving high levels of DLC exposure; uncertainty remains about potential adverse health effects from chronic low-level exposure that might be observed in the general population.

Levels of DLCs in the environment and in foods have been declining over the past few decades. According to studies done between 1998 and 1999 in two Canadian cities, the average dietary intake of dioxins, furan, and similar substances was 0.62 picograms per kilogram of body weight /day (about 19 pg/kg/month),[6] which is well within the provisional tolerable monthly level of 74 pg/kg/month set by the Joint Expert Committee on Food Additives, an expert group of the World Health Organization and the Food and Agriculture Organization of the United Nations.[71]

The European Food Safety Authority (EFSA) reported excessive levels of dioxins in 8% of over 7,000 food samples from 21 European countries between 1999 and 2008.[8]

Impact of household food preparation and cooking methods

Food selection, preparation, and cooking practices can provide the public with essentially cost-free, low-burden tools to reduce exposure to DLCs. For dairy products, choosing low fat or fat- free dairy products is one way to reduce exposure risk. For fish and meat, selecting low fat items (e.g., lean cuts of beef, pork, and poultry) and releasing DLCs, by cooking or removing the fat portion of foods during food preparation and cooking, can significantly reduce contaminant levels. In order to investigate the impact of household food preparation and cooking methods on the levels of DLCs in food, we conducted a systematic literature review.[9] Among the 26 studies reviewed, three types of household preparation (washing, peeling, trimming) and 13 different cooking methods (baking, barbequing, broiling, charbroiling, deep fat frying, pan frying, grilling, microwaving, roasting (covered and uncovered), salt boiling, poaching, smoking, and steaming) were assessed.

[1] Due to the long half-lives of PCDDs, PCDFs, and coplanar PCBs, the appropriate period over which to average intake of dioxin is therefore months, so the tolerable intake is expressed as a monthly value.

For fish fillets, cooking (inclusive of pan-frying, baking, charbroiling, and deep frying) with both skin-on and skin-off (with and without extra trimming) significantly reduced PCB levels by an average of 35%, with no significant differences between cooking methods.[10-14] Skinning and trimming of raw fish fillets alone reduced total PCB levels by 50% in one study.[15] Armbruster et al.[10] reported that the average PCB reduction for trimming together with cooking (baking, broiling, pan frying, or poaching) was 66.9%, compared with 59.4% for trimming alone. Several studies found that PCB reduction was correlated with the fat content of food.[16-18] Voiland Jr. MP et al.[19] reported statistically significant positive correlations between fat content and contaminant levels in both standard and trimmed fillets ($p<0.05$). Moya et al.[20] investigated the effect of the position of the fillet segment in the fish body on PCB levels, but no significant differences were detected. Increasing fillet surface area (from 4×7.5 cm to 4×10 cm) and final internal temperature (from 60°C to 80°C) also reduced TCDD levels. Thus, trimming and cooking of fish fillets, as well as increasing surface area and final internal temperature, will reduce total DLC levels (Table 1).

Evidence showing the effect of cooking and preparation on DLC levels in meat is inconsistent. Petroske et al.[21] and Hori et al.[22] reported that pan frying reduced the amount of PCDD/Fs in hamburger patties by 40% to 50%, if the pan fats and juices were discarded. Thorpe et al.[23] did not find such a reduction. However, the loss of lipids was correlated with the loss of PCDD/Fs during cooking.[21, 24] Thus, cooking of animal meats, in addition to the disposal of pan drippings and poaching/boiling liquids, may help reduce DLC levels (Table 2).

DLC levels in green vegetables were reduced by an average of 56.7% after washing, and by 73.5% after washing followed by boiling.[23,25] Thus, ordinary cooking processes can be expected to reduce DLC levels in these foods (Table 3).

Cooking convenience foods (e.g., canned or jarred) in a saucepan reduced furan levels to a greater extent than cooking in a microwave oven.[21,26] For either cooking method, mean furan levels declined an additional 57.2% with standing and 78.9% with stirring after heating, due to the volatility of furans (Table 4).[21,26]

The impact of household food preparation and cooking methods are summarized in Tables 1 through 4.

Discussion and Conclusions

The impact of household preparation and cooking methods on the levels of DLCs varies by the cooking process, the specific food item, and the type of compounds present.[27] Releasing or removing the fat portion of foods during preparation and cooking can significantly reduce DLC levels.[23] Although it is important to communicate information to the public, methods of reducing contaminant levels in food and messages on food health risks and benefits can be conflicting or confusing. Most studies reviewed showed no significant difference between household preparation and cooking methods. However, some cooking methods should be considered with caution. For example, the reduction of contaminant exposure by deep frying should be balanced against the substantial increase in caloric content and the possible increase in trans and saturated fat intake, depending on the type of frying oil used. Although smoking of fish decreases total PCB levels, it also produces polycyclic aromatic hydrocarbons (PAHs) and can increase the dioxin and furan content.[12,28]

In addition to being an excellent source of beneficial compounds such as omega-3 fatty acids, oily fish (e.g., salmon, sardines, tuna) are a potential source of DLCs and other contaminants. Although removal of fat can reduce DLC levels significantly, such practices also reduce fat-soluble nutrients and other beneficial compounds. Therefore, it is essential to carefully consider both risks and benefits in any public health message regarding food consumption.[29-31]

Table 1: *Effect of household food preparation and cooking methods on DLCs in fish*

Type of Fish	Contaminant Level in Raw Food (µg/g or ppm)	Food Preparation or Cooking Method							
		Trimming	Pan Frying	Deep Frying	Charbroiling Broiling	Roasting	Baking	Boiling/ Poaching	Smoking
Winter Flounder[20]	0.014 – 4.0 for 17 PCB congeners		N.S ↓ PCBs	↓ PCBs by avg. 47%*	N.S ↓ PCBs				
Lake Trout (lean trout)[12]	0.39 – 0.82 total PCBs (skin off, trimmed)				↓ PCBs by 10%*		↓ PCBs by 14%*	↓ PCBs by 10%*	↓ PCBs by 41%*
Siscowets (fat trout)[12]	1.03 total PCBs (skin on, belly flap removed) 0.89 total PCB (skin off, trimmed)				↓ PCBs by 32%*		↓ PCBs by 18%*	↓ PCBs by 19%*	↓ PCBs by 37%*
Brown Trout[19]	1.05 total PCBs	↓ PCBs by 45.6%***							
Chinook Salmon[15]	1.34 – 1.39 total PCBs (skin on, belly flap removed)				↓ PCBs by 44.5%*		↓ PCBs by 37%*		
Carp[15]	1.27 – 2.51 total PCBs (skin on, belly flap removed)		↓ PCBs by 36.8%*	↓ PCBs by 30%*					
Walleye[14]	0.20-0.42 total PCBs (skin on; belly flap removed)			↓ PCBs by 14.6%	↓ PCBs by 25%		↓ PCBs by 18.9%		
White Bass[14]	0.50 – 0.76 total PCBs (skin on, belly flap removed)		↓ PCBs by 28.3%						
Striped Bass[11]	0.956 dry weight (raw, skinned fillet)		↓ PCBs by 14.8%			↓ PCBs by 12.1%	↓ PCBs by 20.6%	↓ PCBs by 12.9%	
Blue Crab[33]	0.269-0.434 total PCBs							↓ PCBs by 29%* w hp ↓ PCBs by 33.1%* w/o hp	
Bluefish[10, 16]	0.47 total PCBs (standard untrimmed fillet)[10] 2.04 ± 0.70 total PCBs (standard untrimmed fillet)[16]	↓ PCBs by avg. 27%*[16]	↓ PCBs by 67.9%*[,b, 10]			↓ PCBs by 71.4%*[,b,10]	↓ PCBs by 67.7%*[,b,10]	↓ PCBs by 60.4%*[,b,10]	
Restructured Carp Fillets[34]	0.000037-0.000046 2378-TCDD (restructured carp fillet)				7.5 cm: ↓ PCBs by 57.3%**** (60°C), 62.8%**** (80°C); 10 cm: ↓ PCBs by 69.1%**** (80°C)	7.5 cm: ↓ PCBs by 42.8%****[,c], 40.6%**** (60°C), 59.2%****[,c], 57.1%**** (80°C); 10 cm: ↓ PCBs by 62.6%**** (80°C)			
Canned Mackerel Pike[35]	Canned mackerel pike: 0.0137 furan							↓ furan by 77.37%****[,d]	
Canned Tuna[35]	Canned tuna: 0.0126 furan							↓ furan by 80.56%**[,d]	

Notes:
[a] hp = hepatopancreas; w = with; w/o = without
[b] Cooking followed trimming process
[c] Fillets are covered when roasted
[d] Heating at 100°C without a lid
[e] Only studies with statistical analysis are included
[f] Trimmed fillet = Skin off, belly flap & lateral line fat removed; Standard fillet = Skin on, belly flap removed

Legend:

Blank	No studies/analysis available
↑	Increase in DLC levels
↓	Decrease in DLC levels
N.S.	Not significant
*	Significant at p<0.05
**	Significant at p<0.01
***	Significant at p<0.001

Table 2: *Effect of household food preparation and cooking methods on DLCs in meat*

Type of Meat	Raw Food Contaminant Levels (pg/g or ppt)	Food Preparation or Cooking Method							
		Pan Frying/ Frying	Grilling/ Broiling	BBQ	Oven	Microwave	Pressure Cooker/ Boiling	Stove Top	Roasting
20% fat ground beef hamburgers (steers from feeding study)[21]	41.2 control patty; 51.3 treated patty from PCDD/F dosed steers. (for 7 PCDDs and 10 PCDFs)	↓ PCDD/F by 42–53.5%							
Beef (single steer)[23]	3.8 for 3 PCDDs and 2 PCDFs	↓ PCDD/F by 7.2%	↓ PCDD/F by 19.2%	↓ PCDD/F by 18.1%	↓ PCDD/F by 7.0%	↓ PCDD/F by 5.3%	↓ PCDD/F by 7.1%	↓ PCDD/F by 27.7%	
Beef[25]	Avg. 0.13 (TEQ) for DLC		↓ DLC by 18.5% (beef slice) ↓ DLC by 17.8% (beef hamburger)				↓ DLC by 29.6%		
Ground Beef[24]	7.507 for DLC		↓ DLC by 48%[17] ↓ PBDE 70.3%[24]						
Veal Steak[27]	0.037 (WHO-TEQ) fresh weight for PCDD/F	↓ PCDD/F by 62.2%	↓ PCDD/F by 81.1%						
Loin of Pork[27]	0.018 (WHO-TEQ) fresh weight for PCDD/F	↓ PCDD/F by 27.8%	↓ PCDD/F by 33.3%						
Korean Seasoned Pork[35]	45,000 for furan							↓ furan by 30.01%*,[a] ↓ (50°C), furan by 46.23%*,[a] (70°C)	
Bacon[17]	7.507 for DLC		↓ DLC by 56%						
Chicken[27]	0.005 (WHO-TEQ) fresh weight for PCDD/F								
Ground Lamb[24]	41.2 wet weight for PBDE		↓ PBDE by 61.9%						
Lamb[27]	0.006 (WHO-TEQ) fresh weight for PCDD/F	↑ PCDD/F by 150%	↓ PCDD/F by 77.8%						

Note: [a] Heating without a lid

Legend:

Blank	No studies/analysis available
↑	Increase in DLC levels
↓	Decrease in DLC levels
-	No effect on DCL levels
*	Significant at p<0.05

Table 3: *Effect of household food preparation and cooking methods on DLCs in vegetables*

Type of Vegetables	Raw Food Contaminant Levels (pg/g or ppt)	Food Preparation and Cooking Methods		
		Washing	Washing+Boiling	Washing+Peeling
Spinach[25]	11.4 for 7 PCDD, 10 PCDFs, 3 DL-PCB	↓ Total DLC by 33.8%*	↓ Total DLC by 61.5%*	
Komatsuna[36]	48.6 for all 29 DLCs (for 7xPCDD; 10xPCDF; 12xPCB)	↓ Total DLC by 79.6%***	↓ Total DLC by 84.6%***	
Organic carrots[37]	1,380 for 24 PCBs			↓ PCB by 83.1%
Organic potato[37]	1,590 for 24 PCBs			↓ PCB by 78.4%

Legend:

Blank	No studies/analysis available
↓	Reduction in DLC levels
*	Significant at p<0.05
***	Significant at p<0.005

Table 4: *Effect of household food preparation and cooking methods on DLCs in convenience foods*

Type of Convenience Foods	Raw Food Contaminant Levels (µg/kg or ppb)	Food Preparation and Cooking Methods			
		Cook in Saucepan	Cook in Microwave	Standing after Heating	Standing after Stirring
Canned soups, canned beans, packed convenience meals, baby foods[26]	Canned beans: 59 on average for furan Convenience meals: 351.38 on average Baby foods: up to 112	↓[a]	↓[a]	↓ furan by 57.2%	↓ furan by 78.9%

Note: [a] In general, furan levels decreased more when foods were cooked in a saucepan, as compared with the same foods cooked in a microwave oven.

Legend:

↓	Reduction in DLC levels

Evidence Gaps

Research on the impact of household food preparation and cooking methods, on DLC levels in meat and vegetables, is limited. The majority of published studies focus on fish and total PCBs, not the specific congeners that make up DLCs. However, when compared to meats, fish contributes less to total DLC intake from food.[32] Hence, further research on the impact of household preparation and cooking on meats and vegetables and the dynamics of DLC reduction is needed in order to develop effective strategies to minimize dietary exposure to DLCs. Methods to better assess risks and benefits in foods and how to effectively communicate these messages to the public are also important.

For More Information:

Specific Guide for Cleaning and Cooking Instructions to Reduce Dioxin, PCBs, and DDT in Fish: http://www.maine.gov/dhhs/eohp/fish/fishprep.htm

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