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Chemical Hazard Evaluation

Polycyclic Aromatic Hydrocarbons in Food

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EXECUTIVE SUMMARY

This study aims to determine the levels of polycyclic aromatic hydrocarbons (PAHs) in selected food items available in the local market.

2. PAHs constitute a large class of organic compounds containing two or more fused aromatic rings. They are primarily formed by incomplete combustion or pyrolysis of organic matter and during various industrial processes. PAHs can enter the food chain either through environmental contamination or by formation during food processing (such as drying and smoking) or cooking (such as grilling, roasting, barbecuing, baking). For non-smokers, the major route of exposure to PAHs is consumption of food.

3. Some PAHs have been shown to be genotoxic, carcinogenic, immunosuppressive and affect development of experimental animals. The Joint Food and Agriculture Organization (FAO) / World Health Organization (WHO) Expert Committee on Food Additives (JECFA) considered in 2005 that 13 individual PAHs are clearly carcinogenic and genotoxic. On the other hand, International Agency for Research on Cancer (IARC) has evaluated some PAHs and classified benzo[a]pyrene (BaP) as Group 1 (carcinogenic to human), while several PAHs were classified as Group 2A (probably carcinogenic to humans), or Group 2B (possibly carcinogenic to humans).

Results

4. In this study, 300 samples were collected and analyzed. About 74% samples (223 samples) were detected with at least one of the targeted PAHs. The predominant PAH found in the samples of this study was chrysene (CHR) (16.9%),

followed by cyclopenta[cd]pyrene (CPP) (14.4%) and benzo[c]fluorene (BcFL) (11.2%). Amongst all samples collected, the levels of total PAH ranged from not detected to 120 mcg/kg. Regarding PAHs in different food groups, “spices” contained the highest mean level, followed by “meat and poultry” and “oils and fats”. Combining the food consumption data captured from the Second Hong Kong Population-based Food Consumption Survey (2nd FCS), the food group “cereal and cereal products” is the major contributor to the dietary exposure to PAHs for the adult population.

5. It is noted that BaP is of more concern among various PAHs, and PAH4* is often used as indicator of the occurrence of the European Union (EU) priority PAHs (which is the same as the 16 PAHs covered in this study) in food. In this study, the calculated margin of exposure (MOE)† values for both BaP and PAH4 are above 10 000, which indicates that the current dietary exposure to PAHs for the Hong Kong adult population is of low public health concern.

Conclusions and Recommendations

6. Comparing the results of the current study with that of the other places, the dietary exposure to PAHs of the local adult population is at the low end of the reported range of exposures.

7. The findings of dietary exposures to PAHs in the present study did not justify changes to the basic dietary advice on healthy eating. The public is advised

* PAH4 is the sum of BaP, CHR, Benz[a]anthracene (BaA) and Benzo[b]fluoranthene (BbFA).

† The MOE is a tool used for considering possible safety concerns arising from the presence in food of substances which are both genotoxic and carcinogenic and no health-based guidance value can be established. The magnitude of a MOE only indicates a level of concern but does not quantify risk.

to maintain a balanced and varied diet so as to avoid excessive exposure to any contaminants, including PAHs, from a small range of food items.

8. The food trade is recommended to take measures to minimize introduction of PAHs in their food products during processing by making reference to the relevant Code of Practice adopted by the Codex Alimentarius Commission (Codex) in 2009 in accordance with the principle of as low as reasonably achievable.

Risk Assessment Studies –

Polycyclic Aromatic Hydrocarbons in Food

OBJECTIVES

This study aims to determine the levels of polycyclic aromatic hydrocarbons (PAHs) in selected food items available in local market, estimate the dietary exposure to PAHs of local adult population arising from consumption of these food items, and assess the associated health risk.

BACKGROUND

2. PAHs constitute a large class of organic compounds containing two or more fused aromatic rings. They are primarily formed by incomplete combustion or pyrolysis of organic matter and during various industrial processes. PAHs are lipophilic and chemically stable. They generally occur in complex mixtures which composition varies with the generating process[1,2]. Due to concerns on carcinogenic and genotoxic potential of these compounds, overseas counterparts have conducted studies on PAHs and have taken action to monitor and control the level of benzo[a]pyrene (BaP) and certain PAHs in food.

Occurrence of PAHs

3. Hundreds of individual PAHs are present in the environment as pollutants. Natural and anthropogenic sources of PAHs are numerous. Primary natural emission sources of PAHs include forest fires, volcanoes and hydrothermal processes. On the other hand, incomplete combustion of wood and fossil fuels, vehicular exhausts, incineration, industrial production, and cigarettes are examples of anthropogenic sources[2, 3]. Humans are exposed to PAHs through different pathways. For smokers, the contribution from smoking can be significant; for non-smokers the major route of exposure is consumption of food[2].

Sources of PAHs in Foods

4. PAHs can enter the food chain either through environmental contamination or by formation during food processing or cooking. For example, PAHs in the air can deposit on crops, especially those with broad leaves. PAHs in contaminated water can be deposited and transferred to fish and marine invertebrates, in particular bivalves fed by filtering large quantities of water. On the other hand, PAHs can be formed during food processing (such as drying and smoking), as well as cooking at high temperature (such as grilling, roasting, barbecuing, baking)[1,2,3].

5. The occurrence of PAHs in food has been investigated in various studies in many countries. According to these studies, meat and fish products, particularly

grilled and barbecued products, oils and fats, cereals and dry foods were found to have higher levels of PAHs[1,2,3,4,5].

Toxicity

Absorption and metabolism

6. Absorption of PAHs in the diet is determined by a number of factors such as the size and lipophilicity of the molecule, dose ingested and lipid content of the food[1]. After being absorbed, PAHs are rapidly distributed to almost all organs and are able to cross the placental barrier. PAHs are extensively metabolised in mammals and do not bioaccumulate[2]. PAHs are metabolized by oxidation of the aromatic rings. Oxidation can generate electrophilic metabolites that bind covalently to nucleic acids and proteins. Some PAHs and some metabolites of PAHs can also bind to the aryl hydrocarbon receptor, resulting in up-regulation of several of the enzymes involved in PAHs metabolism. This may lead to complex and potentially non-linear dose-response relationships for mixtures of PAHs[1]. Most PAHs metabolites are excreted in urine and feaces[1,2].

Toxicity

7. Some PAHs have been shown to be genotoxic, carcinogenic, immunosuppressive and affect development of experimental animals.

8. Amongst the toxicological effects of PAHs, the carcinogenic and genotoxic potential of these compounds has caused most concern. For example, BaP, when administered by the oral route, has been reported to produce tumours of the gastrointestinal tract, liver, lungs and mammary glands of mice and rats. The Joint Food and Agriculture Organization (FAO) / World Health Organization (WHO) Expert Committee on Food Additives (JECFA) considered in 2005 that 13 individual PAHs are clearly carcinogenic and genotoxic[1]. On the other hand, International Agency for Research on Cancer (IARC)[‡] has evaluated some PAHs. BaP was classified as Group 1 (carcinogenic to human), while several PAHs were classified as Group 2A (probably carcinogenic to humans), or Group 2B (possibly carcinogenic to humans)[6]. Table 1 summarized the result of evaluation by IARC and JECFA regarding the carcinogenic and genotoxic effects of 15 PAHs.

9. There is limited or no evidence on the reproductive toxicity of individual PAHs, other than BaP, in animals. Impaired fertility was seen in the offspring of female mice given BaP by gavage at doses >10mg per kg body weight per day. Developmental toxicity of BaP was observed in mice of a susceptible genotype following administration of 120 mg BaP per kg body weight per day via the diet. A no-observed-adverse-effect level (NOAEL) for reproductive and developmental effects via the oral route has not been established [1,2].

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‡ The major role of IARC is to identify causes of cancer (i.e. hazard identification) which is the first fundamental step to understand the carcinogenicity of an agent by identifying its specific properties and its potential to cause cancer. IARC classifications reflect the strength of scientific evidence as to whether an agent can cause cancer in humans, but they do not reflect the risk of developing cancer at a given exposure level. IARC classifies carcinogens and potential carcinogens into one of four categories:
• Group 1: Carcinogenic to humans (e.g. processed meat, tobacco, alcoholic beverages)
• Group 2A: Probably carcinogenic to humans (e.g. red meat, acrylamide)
• Group 2B: Possibly carcinogenic to humans (e.g. aspartame, pickled vegetables)
• Group 3: Not classifiable as to its carcinogenicity in humans (e.g. coffee drinking)

10. In a study on immunosuppressive effects in rats administered BaP by gavage, a NOAEL of 3 mg per kg body weight per day has been identified[7].

Table 1. Toxicity of some PAHs

PAHs	**Abbreviation**	**IARC evaluation**	**JECFA evaluation**
Benzo[a]pyrene	BaP	Group 1	Carcinogenic and genotoxic
Dibenz[a,h]anthracene	DBahA	Group 2A	Carcinogenic and genotoxic
Dibenzo[a,l]pyrene	DBalP	Group 2A	Carcinogenic and genotoxic
Benz[a]anthracene	BaA	Group 2B	Carcinogenic and genotoxic
Benzo[b]fluoranthene	BbFA	Group 2B	Carcinogenic and genotoxic
Benzo[j]fluoranthene	BjFA	Group 2B	Carcinogenic and genotoxic
Benzo[k]fluoranthene	BkFA	Group 2B	Carcinogenic and genotoxic
Chrysene	CHR	Group 2B	Carcinogenic and genotoxic
Dibenzo[a,h]pyrene	DBahP	Group 2B	Carcinogenic and genotoxic
Dibenzo[a,i]pyrene	DBaiP	Group 2B	Carcinogenic and genotoxic
Indeno[1,2,3-cd]pyrene	IP	Group 2B	Carcinogenic and genotoxic
5-methylchrysene	MCH	Group 2B	Carcinogenic and genotoxic
Dibenzo[a,e]pyrene	DBaeP	Group 3	Carcinogenic and genotoxic
Cyclopenta[cd]pyrene	CPP	Group 2A	Genotoxic
Benzo[ghi]perylene	BghiP	Group 3	Genotoxic

Health-based Guidance Value

11. As some PAHs are genotoxic, JECFA considered that it is not possible to assume a threshold mechanism and a health-based guidance value could not be established. Instead, when JECFA evaluated the toxicity of PAHs in 2005, based on information available at that time, it has decided to apply a surrogate approach by using BaP as a marker of dietary exposure as well as genotoxic and carcinogenic effects of 13 PAHs being evaluated. A benchmark dose lower bound for a 10% extra risk ($BMDL_{10}$) equivalent to 100 mcg of BaP of body weight per day were derived for PAHs in food on the basis of a study of carcinogenicity in mice treated

orally with mixtures of PAHs representatives of the genotoxic and carcinogenic PAHs present in food. The margin of exposure (MOE) approach was applied to assess possible health concerns[1]. The lower the MOE value, the greater is the possible effect on public health.

12. Subsequently, European Food Safety Authority (EFSA) conducted further evaluation on PAHs in 2008 and revealed that BaP is not a suitable indicator for the occurrence of 16 European Union (EU) priority PAHs in food. Instead, PAH4 and PAH8[§] were considered the most suitable indicators for the 16 EU priority PAHs in food, with PAH8 providing little added value compared to PAH4. In the evaluation, a MOE approach was adopted to assess possible health concerns by using the lowest $BMDL_{10}$ values calculated with a range of statistical models. These $BMDL_{10}$ values were 0.07 and 0.34 mg per kg body weight per day for BaP and PAH4 respectively. A MOE higher than 10 000 would indicate a low public health concern[2].

Regulatory Control

13. Internationally, the Codex Alimentarius Commission (Codex) has not established any standards for PAHs in food. However, some jurisdictions have established relevant standards for PAHs in certain foods. For example, the Mainland China has established maximum limit for BaP on 5 types of foods[8]. EU has also established maximum level for BaP and PAH4 in certain types of foods[9].

[§] PAH4 is the sum of BaP, CHR, BaA and BbFA;
PAH8 is the sum of PAH4, BkFA, BghiP, DBahA and IP

In Hong Kong, the Harmful Substances in Food Regulations (Cap. 132AF) stipulated that the maximum concentration of BaP present in oil or fat or any mixture of oil and fat is 5mcg/kg[10].

14. As a risk management approach to address the issue of PAHs contamination in smoked and dried foods, Codex developed a “Code of Practice for the Reduction of Contamination of Food with Polycyclic Aromatic Hydrocarbons (PAH) from Smoking and Direct Drying Processes” (Code of Practice) to provide authorities, producers and manufacturers with guidance to reduce contamination of PAHs in foods in 2009[11].

SCOPE OF STUDY

15. To estimate the dietary exposure to PAHs of the local adult population, this study focused on analysis of foods which have been reported to contain PAHs, which were chosen mainly based on (i) their PAHs levels or their contribution to overall PAHs exposure as reported in the literature, (ii) their popularity among the local population, and (iii) their availability in the local market during the sampling period. These samples were classified into 9 different food groups, namely “cereal and cereal products”, “vegetables”, “meat and poultry”, “fish and aquatic products”, “dairy products and eggs”, “snacks and confection”, “oils and fats”, “beverages”, and “spices”.

16. A total of 16 individual PAHs were covered in this study (Table 2). This was the same as the list of PAHs being evaluated by EFSA in 2008 (i.e., “EU

priority PAHs"), and has also covered those PAHs considered to be genotoxic or carcinogenic by JECFA, as well as those PAHs recommended by JECFA to be included in monitoring and BcFL suggested to be analysed in food.

Table 2. 16 PAHs covered in this study

	PAH	Abbreviation		PAH	Abbreviation
1	Benz[a]anthracene*	BaA	9	Dibenz[a,h]anthracene*	DBahA
2	Benzo[b]fluoranthene*	BbFA	10	Dibenzo[a,e]pyrene*	DBaeP
3	Benzo[j]fluoranthene*	BjFA	11	Dibenzo[a,h]pyrene*	DBahP
4	Benzo[k]fluoranthene*	BkFA	12	Dibenzo[a,i]pyrene*	DBaiP
5	Benzo[ghi]perylene	BghiP	13	Dibenzo[a,l]pyrene*	DBalP
6	Benzo[a]pyrene*	BaP	14	Indeno[1,2,3-cd]pyrene*	IP
7	Chrysene*	CHR	15	5-methylchrysene*	MCH
8	Cyclopenta[cd]pyrene	CPP	16	Benzo[c]fluorene#	BcFL

* JECFA recommended to be included this PAH in monitoring
# JECFA suggested to analyse this PAH in food

METHODOLOGY AND LABORATORY ANALYSIS

Methodology

17. A total of 300 food samples were collected from local retailers (such as supermarkets, online shops, grocery stores and wet market stalls) and food premises between September to December 2022 in Hong Kong. A total of 60 food items were included in the sampling list. For each food item, 5 samples were collected. The food items collected are listed in Table 3. Food samples that were not ready-to-eat were prepared in the form of the food "as consumed" before chemical analysis. Only the edible portions of the samples were analysed.

Table 3. Food items collected in the study

Food group	Food items	No. of samples
Cereal and cereal products	White rice, instant noodles, other noodles/pasta, breakfast cereal, oats, buns, sandwich bread	35
Vegetables	Chinese flowering cabbage, lettuce, fruiting vegetables, potato, legumes, pulses, dried mushroom, dried vegetables	40
Meat and poultry	Barbecued pork, roasted pork, roasted duck/goose, smoked sausage, smoked ham/bacon, dried pork, dried beef, grilled chicken, grilled meat	45
Fish and aquatic products	Smoked salmon, abalone, clam, oyster, mussel, scallop, freshwater fish, seawater fish, dried seafood/fish, dried seafood snack	50
Dairy products and eggs	Plain milk, milk powder, cheese, eggs	20
Snacks and confection	Dried fruits, chocolate, potato chips, desiccated coconuts, roasted nuts	25
Oils and fats	Olive oil, peanut oil, canola oil, corn oil, rice bran oil, sunflower seed oil, grapeseed oil, sesame seed oil, margarine, butter	50
Beverages	Ready to drink coffee, instant/ground coffee, prepackaged tea drink, tea leaves/bag, cocoa/chocolate drink	25
Spices	Pepper, curry powder	10
Total (9 groups)	**(60 food items)**	**300**

18. The analytical result for BaP, which is of more concern among various PAHs, as well as the analytical result for PAH4, which is often used as indicator of the occurrence of the EU priority PAHs in food, were combined with the food consumption information captured from the Second Hong Kong Population-based Food Consumption Survey (2nd FCS) to obtain the dietary exposures of local adult population. Estimation of dietary exposures was performed with the aid of an in-house developed web-based computer system, Exposure Assessment System

(EASY). The mean and 90th percentile exposure levels were used to represent the dietary exposure levels of average and high consumers of the local adult population, respectively. The MOE values were calculated by dividing the reference dose by the estimated dietary exposure to respective PAHs from food. The reference dose ($BMDL_{10}$) applied for BaP and PAH4 were 0.07 mg/kg bw/day and 0.34 mg/kg bw/day, respectively[2].

Laboratory Analysis

19. Laboratory analysis of PAHs was conducted by the Food Research Laboratory (FRL) of the Centre for Food Safety (CFS). In this project, 300 samples of different foods were tested for 16 individual PAHs.

20. The PAHs levels in samples were analysed by gas chromatography - high resolution mass spectrometry (GC-HRMS). Stable isotope labelled PAHs were spiked quantitatively as internal standards into a measured amount of sample. The PAHs were extracted by ultra-sonication with organic solvent(s), followed by exchange with non-polar solvent. The PAHs in non-polar solvent was cleaned up with solid phase extraction (SPE) cartridges before instrument analysis. The limits of detection (LODs) of the individual PAHs were 0.05 mcg/kg.

Treatment of Analytical Values Below the LOD

21. In this study, data were treated with both lower bound (LB) and upper bound (UB) approach. This approach compares the two extreme scenarios, based on the consideration that the true value for results less than LOD may actually be any value between zero and the achieved LOD. The LB scenario assumes that the chemical is absent; therefore, to results reported as <LOD a value of zero is assigned. The UB scenario assumes that the chemical is present at the level of the LOD; thus, to results reported as <LOD a value of the corresponding LOD is assigned.

RESULTS AND DISCUSSION

Occurrence of PAHs

22. Of the 300 samples analysed, 223 samples (about 74%) were detected with at least 1 PAH, while the remaining 77 samples (about 26%) were not detected with any of the 16 PAHs. However, most samples were only detected with a small number of individual PAHs. Among those samples detected with PAHs, 68% were detected with 4 or less individual PAHs, 28% only detected with 1 PAH. Similar to the finding of some other studies[1,4], the predominant PAH found in the samples of this study was CHR (16.9%). This was followed by CPP (14.4%), BcFL (11.2%), BaA (10.6%) and BbFA (7.8%). On the other hand, DBahP and MCH were not detected in all collected samples. The concentrations of 16 PAHs and their total amount (total PAH) in the food samples are summarized in Table 4.

Table 4. Occurrence of different PAHs in food samples (mcg/kg)

	Samples <LOD (%)	Mean (LB-UB) (mcg/kg)	Minimum (mcg/kg)	Maximum (mcg/kg)
BaA	65	0.24-0.27	ND	17
BbFA	74	0.16-0.20	ND	9.2
BjFA	82	0.097-0.14	ND	7.4
BkFA	88	0.056-0.10	ND	7.4
BghiP	58	0.15-0.18	ND	8.3
BaP	82	0.13-0.17	ND	15
CHR	61	0.40-0.43	ND	19
CPP	89	0.31-0.36	ND	39
DBahA	99	0.0013-0.051	ND	0.16
DBaeP	99	0.0015-0.051	ND	0.13
DBahP		<LOD in all samples		
DBaiP	99	0.00057-0.050	ND	0.12
DBalP	99	0.00070-0.050	ND	0.11
IP	89	0.072-0.12	ND	8.5
MCH		<LOD in all samples		
BcFL	49	0.26-0.29	ND	5.9
PAH4	49*	0.92-1.1	0-0.20 (LB-UB)	57-57 (LB-UB)
Total PAH	26*	1.9-2.5	0-0.80 (LB-UB)	120-120(LB-UB)

* Concentration of all individual PAHs are < LOD
** Rounded to 2 significant figures

23. The range of concentrations of BaP, PAH4 and total PAH for the 9 food groups in this study are summarized in Table 5 below. Details of individual food items are shown in Appendix I.

Table 5. Range of concentration of PAHs in different food groups

Food group	No. of samples	BaP (LB) (mcg/kg)	PAH4 (LB) (mcg/kg)	Total PAH (LB) (mcg/kg)
Cereal and cereal products	35	0-0.090	0-0.63	0-0.99
Vegetables	40	0-0.060	0-0.41	0-0.97
Meat and poultry	45	0-6.0	0-36	0-63
Fish and aquatic products	50	0-0.27	0-7.3	0-11
Dairy and eggs	20	0-0.060	0-0.16	0-0.45
Snacks and confection	25	0-0.40	0-2.8	0-4.8
Oils and fats	50	0-0.93	0-7.0	0-20
Beverages	25	0-0	0-0.100	0-0.37
Spices	10	0.13-15	1.2-57	2.3-120
All samples	**300**	**0-15**	**0-57**	**0-120**

* Rounded to 2 significant figures

24. The study revealed that the ranges (LB) of BaP, PAH4 and total PAH in all food samples collected were 0-15 mcg/kg, 0-57 mcg/kg and 0-120 mcg/kg, respectively. The mean levels (LB-UB) of BaP, PAH4 and total PAH in all food samples collected were 0.13-0.17 mcg/kg, 0.93-1.1 mcg/kg and 1.9-2.5 mcg/kg, respectively. The food group "spices", composed of curry powder and peppers, was found to have the highest PAHs content, with a mean level (LB-UB) of BaP, PAH4 and total PAH of 2.0-2.0 mcg /kg, 10-10 mcg /kg and 19-20 mcg /kg respectively. This is followed by the food groups "meat and poultry" and "oils and fats". In contrast, food groups including "beverages", "dairy and eggs", "vegetables", and "cereal and cereal products" were found to have very low levels of PAHs. The mean total PAH (LB) levels of these food groups were less than 0.22 mcg/kg. Variation in PAHs levels was observed in different food groups. On

the other hand, PAHs concentrations also varied in different samples of the same food item.

25. Variations of PAHs concentrations within food group could be due to different food items were grouped together. For example, levels of PAHs in roasted/grilled meat, smoked meat and dried meat in food group "meat and poultry" were found to have marked difference. Dried meats were found to have highest PAHs, followed by roasted/grill meats and smoked meats. Similarly, in the food group "oils and fats", vegetable oils have higher PAHs contents, followed by margarine, and butter. Amongst the food group "snacks and confection", chocolate was found to have relatively higher PAHs levels, which was followed by desiccated coconuts, dried fruits, potato chips/crisps and roasted nuts.

26. As regards the concentration level of individual food items, pepper was found to have the highest mean level (LB-UB) of BaP, PAH4 and total PAH of 3.2-3.2 mcg/kg, 13-13 mcg/kg and 26-27 mcg/kg respectively. BaP was detected in all 5 pepper samples and at least 5 other individual PAHs were detected in each of these samples. The high PAHs levels in spices agreed well with the findings of other studies [12,13], which remarked that such observation on heterogenous PAHs contaminations among samples may originate from environmental pollution or the drying process. Apart from pepper, it was observed that roasted/grilled meat and dried pork have relatively high level of BaP and total PAH, while dried pork and curry powder were found to have relatively high level of PAH4. The difference in

ranking of food items for their levels of BaP, PAH4 and total PAH is expected due to their PAH profile or their source of PAHs contamination. Since this study only covered 16 EU priority PAHs, it is quite difficult to infer on the source of PAHs in the samples.

27. Bivalve molluscs, which are filter feeders and more likely to accumulate PAHs in water, are found to have higher levels of PAHs than fish. Amongst abalone, clam, mussel, oyster and scallop, the study found oyster to have the highest PAHs levels, followed by clam. PAHs in other bivalves were roughly the same. Besides, BaP was only detected in oyster and clam.

Comparison with Previous Local Study

28. A local study has been conducted in 2004 to investigate the levels of selected PAHs in different barbecue meat samples[14]. Comparison of similar food items in previous local study and the present study (i.e., barbecued pork, roasted pork, roasted duck, dried pork and dried beef) revealed that the BaP and PAH4 levels in samples collected in the present study were generally lower than those in the previous study. In the previous study, the mean (LB) level of BaP and PAH4 of these food items were 0.52 and 4.0 mcg/kg, respectively. On the other hand, the levels in the present study were 0.18 and 2.3 mcg/kg for BaP and PAH4, respectively.

Dietary Exposure to PAHs

29. The dietary exposure estimates to BaP and PAH4 of the local adult population arising from the collected food items, and the corresponding MOE values are shown in Table 6.

Table 6. Dietary exposure to BaP and PAH4 of local adult population and the corresponding MOE values

		Average consumers	**High consumers**
BaP	**Dietary Exposure** (ng/kg bw/day) (LB-UB)	0.13- 0.90	0.21- 1.4
	MOE (LB-UB)	540 000- 78 000	330 000- 51 000
PAH4	**Dietary Exposure** (ng/kg bw/day) (LB-UB)	1.4- 4.2	2.3- 6.3
	MOE (LB-UB)	240 000- 81 000	150 000- 54 000

30. For dietary exposure to BaP of the local adult population, the LB and UB exposure estimates for average consumers are 0.13 and 0.90 ng/kg bw/day, while for high consumers (90^{th} percentile), the LB and UB exposure estimates are 0.21 and 1.4 ng/kg bw/day respectively. Their corresponding MOEs for average and high consumers of the population are in the ranges of 540 000- 78 000 (LB-UB) and 330 000- 51 000 (LB-UB). These MOEs are much higher than 10 000, which indicate a low public health concern.

31. On the other hand, the LB and UB exposure estimates to PAH4 for average consumers are 1.4 and 4.2 ng/kg bw/day, while for high consumers (90^{th} percentile), the LB and UB exposure estimates are 2.3 and 6.3 ng/kg bw/day respectively. Their calculated MOEs for average and high consumers of the population are in the ranges of 240 000- 81 000 (LB-UB) and 150 000- 54 000 (LB-UB) respectively. These MOEs are well above 10 000, indicating a low public health concern.

32. Further analysis of dietary exposures of individual age gender groups of the adult population to BaP and PAH4 is shown in Table 7. In general, the dietary exposure of females is slightly lower than males, likely due to their eating habit. All the MOE values for average and high consumers were above 10 000, indicating low health concern for all age gender groups.

Table 7. Dietary exposure to BaP and PAH4 by age gender groups of local population

		Dietary Exposure to BaP (ng/kg bw/day)		Dietary Exposure to PAH4 (ng/kg bw/day)	
Age-gender group		**Average consumers (LB-UB)**	**High consumers (LB-UB)**	**Average consumers (LB-UB)**	**High consumers (LB-UB)**
Age 18-49	**Male**	0.14-0.88	0.23-1.3	1.5-4.1	2.3-6.1
	Female	0.12-0.86	0.21-1.3	1.4-4.0	2.2-6.0
Age 50-64	**Male**	0.14-0.97	0.22-1.5	1.5-4.5	2.4-6.6
	Female	0.12-0.89	0.20-1.3	1.3-4.1	2.2-6.0
>Age 65	**Male**	0.13-1.0	0.22-1.6	1.5-4.7	2.4-7.1
	Female	0.12-0.86	0.19-1.3	1.4-4.0	2.2-6.1

*Rounded to 2 significant figures

Major Food Contributor

33. Relative contribution of different food groups to BaP and PAH4 exposure at LB estimation for an average consumer of the local population is shown in Table 8 and graphically in Figures 1 and 2. The LB is considered to better reflect the actual food group contribution to BaP and PAH4 exposure since it is not influenced by the high number of examples below LOD in some food groups.

Table 8. Average dietary exposure to BaP and PAH4 of local population and the percentage contribution of different food groups

Food group	BaP		PAH4	
	Dietary Exposure (ng/kg bw/day) (LB)	% Contribution to Dietary Exposure*	Dietary Exposure (ng/kg bw/day) (LB)	% Contribution to Dietary Exposure*
Cereal and cereal products	0.066	51.2%	0.85	59.4%
Vegetables	0.0031	2.4%	0.098	6.8%
Meat and poultry	0.021	16.4%	0.084	5.9%
Fish and aquatic products	0.00092	0.7%	0.084	5.8%
Dairy and eggs	0.00032	0.2%	0.021	1.5%
Snacks and confection	0.0027	2.1%	0.017	1.2%
Oils and fats	0.016	12.6%	0.20	13.7%
Beverages	0	0%	0.0024	0.2%
Spices	0.019	14.4%	0.080	5.6%
Total	**0.13**	**100%**	**1.4**	**100%**

*May not sum to total of 100% due to rounding

Figure 1. Relative contribution of food groups to LB dietary exposure to BaP among local adult population in average

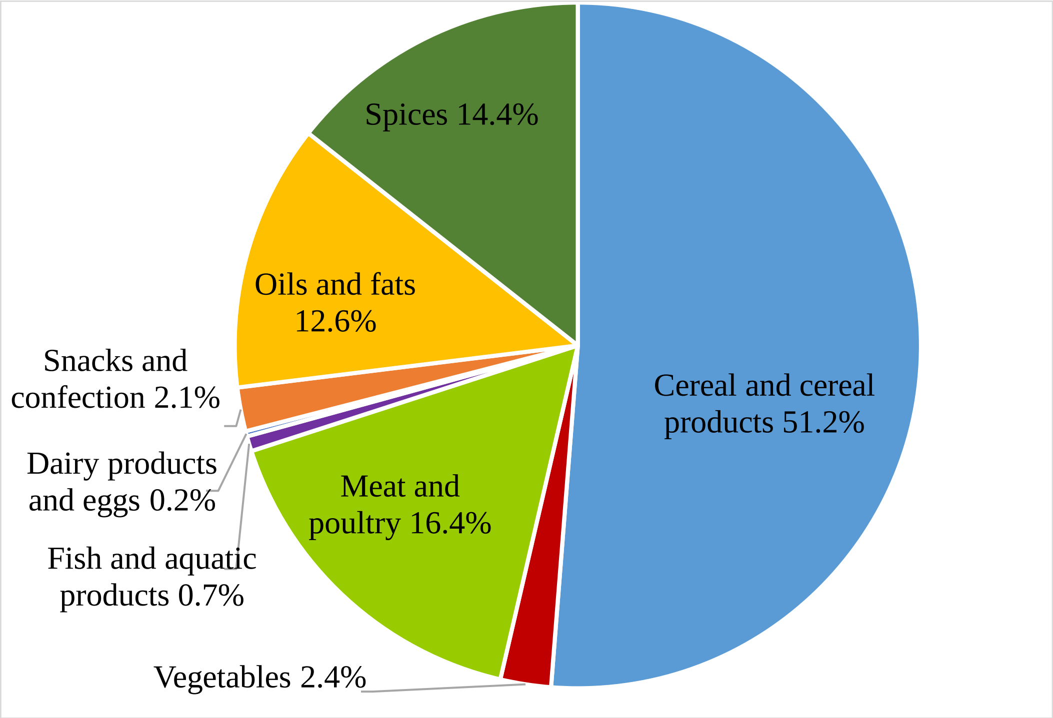
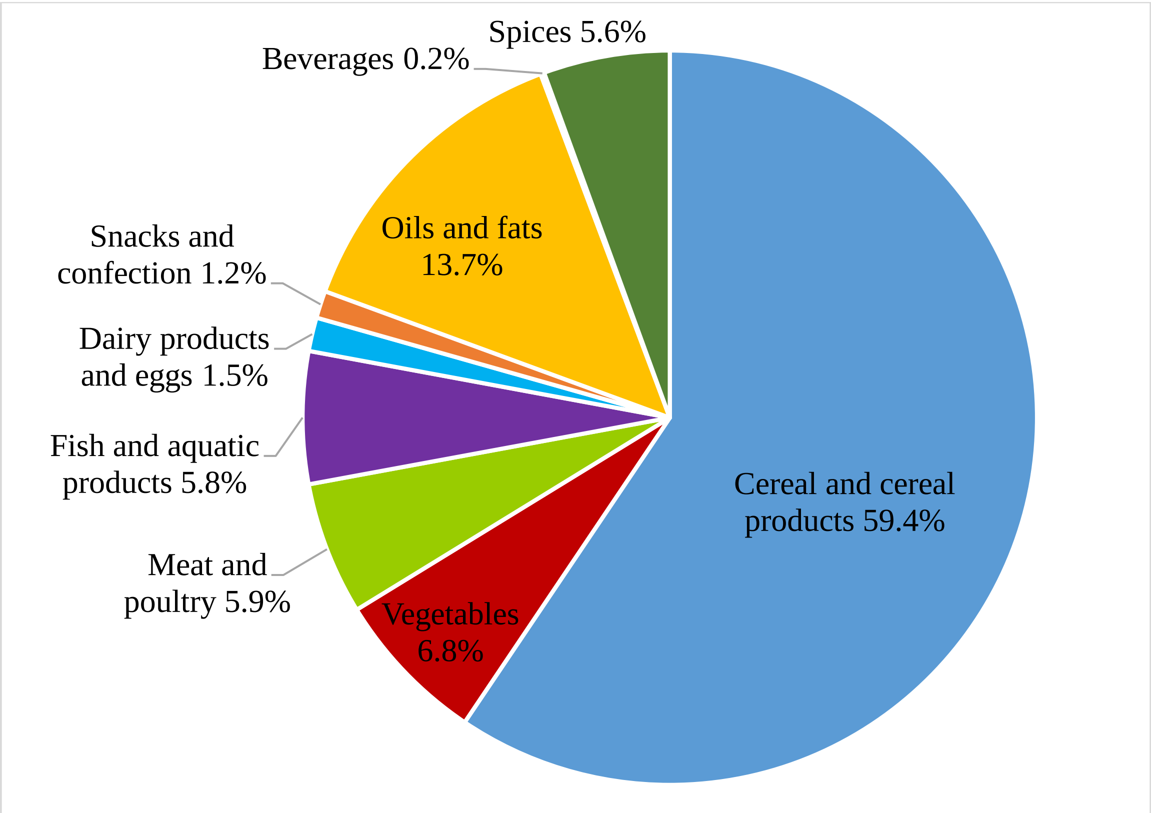


Figure 2. Relative contribution of food groups to LB dietary exposure to PAH4 among local adult population in average



34. In this study, “cereal and cereal products” was found to be the major contributor to PAHs exposure. This food group accounted for 51.2% (i.e. 0.066 ng/kg bw/day at the LB) of the overall exposure of BaP, and 59.4% (i.e., 0.85 ng/kg bw/day at LB) of overall exposure of PAH4. The result is similar to that of Mainland and overseas studies[2,4,15,16].

International Comparison

35. Dietary exposures of PAHs have been reported in recent studies, including those conducted by the China National Center for Food Safety Risk Assessment (CFSA)[4], the European Food Safety Authority (EFSA)[2], French Agency for Food, Environmental and Occupational Health & Safety (ANSES)[17], Food Safety Authority of Ireland (FSAI)[16,18] and Food Standards Australia and New Zealand (FSANZ)[19]. In general, the calculated MOE values in these studies were greater than 10 000. Comparing the results of the current study with that of the overseas studies, the dietary exposures to PAHs of the local population are in the low range.

Table 9. International comparison of average dietary exposure to PAHs and MOE values

Places	BaP		PAH4	
	Dietary Exposure (ng/kg bw/day)	MOE	Dietary Exposure (ng/kg bw/day)	MOE
Mainland China (CFSA)[4]	3.08	22 704	17.61	19 305
EU (EFSA)[2]	3.9	17 900	19.5	17 500
France (ANSES)[17]	0.191	-	1.478	230 000
Ireland (FSAI)[16,18,]	4 [18]	25 000 [18]	1-4.1 [16]	326 393-82 330[16]
Australia (FSANZ)[19]	0.2-1.3 (LB-UB)	500 000-77 000 (LB-UB)	-	-
Hong Kong (CFS)	0.13- 0.90 (LB-UB)	540 000-78 000 (LB-UB)	1.4- 4.2 (LB-UB)	240 000- 81 000 (LB-UB)

Uncertainties and Limitations

36. This study only focused on foods that were reported to have high PAHs levels or have important contribution to PAHs dietary exposure as reported in the literature. It has not covered all foods in the local diet, and might therefore not be able to identify local foods containing high PAHs levels, in particular those consumed in small amount.

37. Although more accurate and precise exposure estimation could be achieved with more samples analysed, compromises had to be made in relation to the use of finite laboratory resources. There is likely batch-to-batch variation in

PAHs levels even for the same product, the results of this study represented only a snapshot of the PAHs levels in the selected locally available foods.

38. As a usual practice, caution should be taken when comparing the results from different studies. Apart from the test methods adopted, other factors such as research methodology, sampling strategies, approaches of capturing and handling consumption data, limit of detection, etc. would affect the outcome of the studies.

CONCLUSIONS AND RECOMMENDATIONS

39. In this study, about 74% samples (223 out of 300 samples) collected were detected with at least one of the targeted PAHs. However, most samples were only detected with a small number of individual PAHs. Among those samples detected with PAHs, 68% were detected with 4 or less individual PAHs, 28% only detected with 1 PAH. Regarding PAHs in different food groups, "spices" contained the highest mean level, followed by "meat and poultry" and "oils and fats". Combining the food consumption data captured from the 2nd FCS, the food group "cereal and cereal products" is the major contributor to the dietary exposure to PAHs for the adult population.

40. Comparing the results of current study with that of the other places, the dietary exposure to PAHs of the local population is at the low end of the reported range of exposures. The calculated MOE values for both BaP and PAH4 are above

10 000, which indicate that current dietary exposure to PAHs for the Hong Kong adult population has low public health concern.

41. The findings of the dietary exposures to PAHs in the present study did not justify changes to the basic dietary advice on healthy eating. The public is advised to maintain a balanced and varied diet so as to avoid excessive exposure to any contaminants, including PAHs, from a small range of food items.

42. The food trade is recommended to take measures to minimize the level of PAHs in their food products by making reference to the relevant Code of Practice adopted by Codex in 2009 in accordance with the principle of as low as reasonably achievable (ALARA).

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Appendix I

Mean levels of BaP, PAH4 and Total PAH (mcg/kg) detected in food samples

Food item	No. of Samples	BaP					PAH4					Total PAH				
		% of samples <LOD	Mean (mcg/kg) [range]				% of samples <LOD	Mean (mcg/kg) [range]				% of samples <LOD	Mean (mcg/kg) [range]			
			Lower bound		Upper bound			Lower bound		Upper bound			Lower bound		Upper bound	
Cereal and cereal products	**35**	**97**	**0.0026**	**[0-0.090]**	**0.051**	**[0.050-0.090]**	**63**	**0.066**	**[0-0.63]**	**0.23**	**[0.20-0.63]**	**37**	**0.22**	**[0-0.99]**	**0.94**	**[0.80-1.5]**
White rice	5	80	0.018	[0-0.090]	0.058	[0.050-0.090]	20	0.21	[0-0.63]	0.32	[0.20-0.63]	20	0.48	[0-0.99]	1.1	[0.80-1.5]
Instant noodles	5	<LOD in all samples					80	0.028	[0-0.14]	0.22	[0.20-0.29]	40	0.21	[0-0.63]	0.95	[0.80-1.3]
Noodles/pasta, other than instant noodles	5	<LOD in all samples					80	0.012	[0-0.060]	0.20	[0.20-0.21]	20	0.17	[0-0.36]	0.92	[0.80-1.1]
Breakfast cereal	5	<LOD in all samples					<LOD in all samples					40	0.082	[0-0.21]	0.83	[0.80-0.91]
Oats	5	<LOD in all samples					<LOD in all samples					<LOD in all samples				
Buns (without filling)	5	<LOD in all samples					20	0.11	[0-0.22]	0.25	[0.20-0.32]	20	0.32	[0-0.80]	0.99	[0.80-1.4]
Sandwich bread	5	<LOD in all samples					40	0.11	[0-0.23]	0.26	[0.20-0.33]	20	0.26	[0-0.43]	0.95	[0.80-1.1]
Vegetables	**40**	**98**	**0.0015**	**[0-0.060]**	**0.050**	**[0.050-0.060]**	**63**	**0.057**	**[0-0.41]**	**0.23**	**[0.20-0.46]**	**28**	**0.19**	**[0-0.97]**	**0.92**	**[0.80-1.7]**
Chinese flowering cabbage	5	<LOD in all samples					80	0.010	[0-0.050]	0.20	[0.20-0.20]	60	0.024	[0-0.070]	0.80	[0.80-0.82]
Lettuce	5	80	0.012	[0-0.060]	0.052	[0.050-0.060]	0	0.24	[0.10-0.41]	0.35	[0.25-0.46]	0	0.52	[0.30-0.90]	1.2	[0.99-1.5]
Fruiting vegetables (including gourds)	5	<LOD in all samples					80	0.016	[0-0.080]	0.21	[0.20-0.23]	60	0.044	[0-0.14]	0.81	[0.80-0.84]
Potato/sweet potato	5	<LOD in all samples					60	0.030	[0-0.080]	0.21	[0.20-0.23]	20	0.098	[0-0.19]	0.85	[0.80-0.89]
Legumes	5	<LOD in all samples					40	0.078	[0-0.21]	0.25	[0.20-0.36]	0	0.38	[0.070-0.97]	1.1	[0.82-1.7]
Pulses (dried)	5	<LOD in all samples					80	0.038	[0-0.19]	0.22	[0.20-0.28]	0	0.22	[0.070-0.39]	0.94	[0.82-1.1]
Dried shiitake mushroom	5	<LOD in all samples					<LOD in all samples					40	0.13	[0-0.35]	0.90	[0.80-1.1]
Dried vegetables	5	<LOD in all samples					60	0.042	[0-0.15]	0.21	[0.20-0.25]	40	0.066	[0-0.22]	0.82	[0.80-0.88]
Meat and poultry	**45**	**80**	**0.24**	**[0-6.0]**	**0.28**	**[0.050-6.0]**	**44**	**1.7**	**[0-36]**	**1.8**	**[0.20-36]**	**20**	**3.6**	**[0-63]**	**4.2**	**[0.80-64]**

Food item	No. of Samples	BaP					PAH4					Total PAH				
		% of samples <LOD	Mean (mcg/kg) [range]				% of samples <LOD	Mean (mcg/kg) [range]				% of samples <LOD	Mean (mcg/kg) [range]			
			Lower bound		Upper bound			Lower bound		Upper bound			Lower bound		Upper bound	
Barbecued pork	5	<LOD in all samples					80	0.020	[0-0.10]	0.21	[0.20-0.25]	0	0.27	[0.070-0.58]	0.99	[0.82-1.3]
Roasted pork	5	<LOD in all samples					80	0.024	[0-0.12]	0.21	[0.20-0.27]	40	0.11	[0-0.29]	0.87	[0.80-0.99]
Roasted duck/goose	5	<LOD in all samples					<LOD in all samples					60	0.14	[0-0.48]	0.91	[0.80-1.2]
Smoked sausage	5	<LOD in all samples					60	0.092	[0-0.35]	0.25	[0.20-0.40]	40	0.46	[0-1.1]	1.2	[0.80-1.6]
Smoked ham/ bacon	5	<LOD in all samples					0	0.20	[0.10-0.34]	0.31	[0.25-0.39]	0	0.55	[0.17-0.82]	1.2	[0.88-1.5]
Dried pork	5	20	0.85	[0-2.3]	0.86	[0.050-2.3]	20	11	[0-36]	11	[0.20-36]	0	16	[0.22-50]	16	[0.92-50]
Dried beef	5	40	0.046	[0-0.10]	0.066	[0.050-0.10]	0	0.57	[0.070-0.91]	0.62	[0.22-0.91]	0	0.89	[0.070-1.7]	1.4	[0.82-2.2]
Roasted/grilled chicken	5	<LOD in all samples					40	0.10	[0-0.25]	0.25	[0.20-0.36]	20	0.22	[0-0.44]	0.90	[0.80-1.0]
Roasted/grilled meat	5	60	1.3	[0-6.0]	1.3	[0.050-6.0]	20	3.0	[0-13]	3.1	[0.20-13]	20	14	[0-63]	14	[0.80-64]
Fish and aquatic products	**50**	**90**	**0.014**	**[0-0.27]**	**0.059**	**[0.050-0.27]**	**48**	**0.52**	**[0-7.3]**	**0.67**	**[0.20-7.3]**	**14**	**1.0**	**[0-11]**	**1.7**	**[0.80-11]**
Smoked salmon	5	<LOD in all samples					60	0.10	[0-0.42]	0.27	[0.20-0.52]	20	0.47	[0-1.6]	1.2	[0.80-2.1]
Abalone	5	<LOD in all samples					60	0.050	[0-0.18]	0.23	[0.20-0.33]	20	0.32	[0-0.61]	1.1	[0.80-1.3]
Clam	5	80	0.016	[0-0.080]	0.056	[0.050-0.080]	40	0.66	[0-1.7]	0.78	[0.20-1.7]	0	0.97	[0.27-2.0]	1.6	[1.0-2.5]
Oyster	5	60	0.098	[0-0.27]	0.13	[0.050-0.27]	0	3.2	[0.63-7.3]	3.3	[0.73-7.3]	0	5.6	[1.4-11]	6.0	[2.0-11]
Mussel	5	<LOD in all samples					80	0.064	[0-0.32]	0.24	[0.20-0.42]	40	0.24	[0-0.86]	0.97	[0.80-1.4]
Scallop/ Fanshell	5	<LOD in all samples					40	0.058	[0-0.12]	0.23	[0.20-0.27]	0	0.30	[0.12-0.47]	1.0	[0.87-1.2]
Freshwater fish	5	<LOD in all samples					80	0.040	[0-0.20]	0.23	[0.20-0.35]	20	0.20	[0-0.49]	0.94	[0.80-1.2]
Seawater fish	5	<LOD in all samples					60	0.086	[0-0.38]	0.25	[0.20-0.44]	0	0.35	[0.18-0.55]	1.0	[0.93-1.2]
Dried seafood and fish	5	<LOD in all samples					40	0.52	[0-1.7]	0.67	[0.20-1.8]	40	1.1	[0-4.1]	1.8	[0.80-4.7]
Dried fish/seafood snack	5	60	0.030	[0-0.080]	0.060	[0.050-0.080]	20	0.35	[0-0.61]	0.45	[0.20-0.62]	0	0.83	[0.41-2.0]	1.4	[1.1-2.5]
Dairy products and eggs	**20**	**95**	**0.0030**	**[0-0.060]**	**0.051**	**[0.050-0.060]**	**85**	**0.014**	**[0-0.16]**	**0.20**	**[0.20-0.26]**	**55**	**0.057**	**[0-0.45]**	**0.83**	**[0.80-1.1]**
Plain milk	5	<LOD in all samples					<LOD in all samples					60	0.046	[0-0.14]	0.83	[0.80-0.89]

Food item	No. of Samples	BaP					PAH4					Total PAH				
		% of samples <LOD	Mean (mcg/kg) [range]				% of samples <LOD	Mean (mcg/kg) [range]				% of samples <LOD	Mean (mcg/kg) [range]			
			Lower bound		Upper bound			Lower bound		Upper bound			Lower bound		Upper bound	
Milk powder	5	<LOD in all samples					<LOD in all samples					<LOD in all samples				
Cheese	5	80	0.012	[0-0.060]	0.052	[0.050-0.060]	80	0.012	[0-0.060]	0.20	[0.20-0.21]	20	0.066	[0-0.12]	0.83	[0.80-0.87]
Eggs	5	<LOD in all samples					60	0.044	[0-0.16]	0.21	[0.20-0.26]	40	0.11	[0-0.45]	0.86	[0.80-1.1]
Snacks and confection	**25**	**64**	**0.065**	**[0-0.40]**	**0.097**	**[0.050-0.40]**	**28**	**0.39**	**[0-2.8]**	**0.51**	**[0.20-2.8]**	**12**	**0.80**	**[0-4.8]**	**1.4**	**[0.80-5.2]**
Dried fruits	5	<LOD in all samples					20	0.26	[0-0.59]	0.37	[0.20-0.63]	0	0.54	[0.27-1.1]	1.1	[0.91-1.6]
Chocolate	5	40	0.15	[0-0.40]	0.17	[0.050-0.40]	20	0.88	[0-2.8]	0.97	[0.20-2.8]	0	1.8	[0.43-4.8]	2.3	[1.1-5.2]
Potato chips/crisps	5	80	0.054	[0-0.27]	0.094	[0.050-0.27]	40	0.25	[0-0.54]	0.39	[0.20-0.63]	40	0.40	[0-0.83]	1.1	[0.80-1.5]
Desiccated coconuts	5	20	0.11	[0-0.32]	0.12	[0.050-0.32]	0	0.44	[0.060-1.6]	0.54	[0.21-1.6]	0	1.1	[0.060-2.9]	1.6	[0.81-3.3]
Roasted nuts	5	80	0.014	[0-0.070]	0.054	[0.050-0.070]	60	0.098	[0-0.29]	0.26	[0.20-0.35]	20	0.27	[0-0.60]	0.98	[0.80-1.3]
Oils and fats	**50**	**62**	**0.10**	**[0-0.93]**	**0.13**	**[0.050-0.93]**	**16**	**1.3**	**[0-7.0]**	**1.4**	**[0.20-7.2]**	**4**	**2.4**	**[0-20]**	**3.0**	**[0.80-21]**
Butter	5	<LOD in all samples					80	0.050	[0-0.25]	0.24	[0.20-0.40]	0	0.65	[0.070-1.4]	1.4	[0.82-2.1]
Olive oil	5	60	0.070	[0-0.19]	0.10	[0.050-0.19]	0	2.1	[0.060-7.0]	2.2	[0.21-7.2]	0	5.4	[0.22-20]	6.1	[0.92-21]
Peanut oil	5	60	0.22	[0-0.93]	0.25	[0.050-0.93]	0	2.1	[0.42-6.2]	2.1	[0.46-6.3]	0	3.7	[0.72-9.9]	4.1	[1.3-10]
Canola oil	5	60	0.034	[0-0.090]	0.064	[0.050-0.090]	0	0.78	[0.22-1.7]	0.82	[0.37-1.7]	0	1.3	[0.22-2.9]	1.9	[0.97-3.4]
Corn oil	5	20	0.14	[0-0.27]	0.15	[0.050-0.27]	0	1.7	[0.45-2.6]	1.7	[0.50-2.6]	0	2.6	[0.45-4.2]	3.1	[1.1-4.5]
Rice bran oil	5	<LOD in all samples					0	2.5	[0.46-4.4]	2.6	[0.61-4.5]	0	3.6	[0.58-6.5]	4.2	[1.3-7.0]
Sunflower seed oil	5	20	0.37	[0-0.56]	0.38	[0.050-0.56]	20	1.8	[0-2.8]	1.9	[0.20-2.8]	0	2.9	[0.070-4.1]	3.3	[0.82-4.4]
Grapeseed oil	5	80	0.088	[0-0.44]	0.13	[0.050-0.44]	0	1.0	[0.060-3.3]	1.1	[0.21-3.3]	0	1.6	[0.11-6.0]	2.2	[0.83-6.4]
Sesame seed oil	5	40	0.092	[0-0.17]	0.11	[0.050-0.17]	20	0.41	[0-0.97]	0.54	[0.20-1.1]	20	1.1	[0-1.9]	1.7	[0.80-2.5]
Margarine	5	80	0.016	[0-0.080]	0.056	[0.050-0.080]	40	0.23	[0-0.55]	0.39	[0.20-0.67]	20	1.5	[0-3.3]	2.1	[0.80-3.9]
Beverages	**25**	**<LOD in all samples**					**96**	**0.0040**	**[0-0.10]**	**0.20**	**[0.20-0.25]**	**84**	**0.034**	**[0-0.37]**	**0.83**	**[0.80-1.1]**
Coffee, ready to drink	5	<LOD in all samples					<LOD in all samples					80	0.050	[0-0.25]	0.84	[0.80-1.0]
Instant / ground coffee	5	<LOD in all samples					<LOD in all samples					<LOD in all samples				

Food item	No. of Samples	BaP					PAH4					Total PAH				
		% of samples <LOD	**Mean (mcg/kg) [range]**				**% of samples <LOD**	**Mean (mcg/kg) [range]**				**% of samples <LOD**	**Mean (mcg/kg) [range]**			
			Lower bound		Upper bound			Lower bound		Upper bound			Lower bound		Upper bound	
Prepackaged tea drink	5	<LOD in all samples					80	0.020	[0-0.10]	0.21	[0.20-0.25]	40	0.12	[0-0.37]	0.89	[0.80-1.1]
Tea leaves/bag	5	<LOD in all samples					<LOD in all samples					<LOD in all samples				
Cocoa/chocolate drink	5	<LOD in all samples					<LOD in all samples					<LOD in all samples				
Spices	**10**	**0**	**2.0**	**[0.13-15]**	**2.0**	**[0.13-15]**	**0**	**10**	**[1.2-57]**	**10**	**[1.2-57]**	**0**	**19**	**[2.3-120]**	**20**	**[2.8-120]**
Pepper	5	0	3.2	[0.13-15]	3.2	[0.13-15]	0	13	[1.2-57]	13	[1.2-57]	0	26	[2.3-120]	27	[2.8-120]
Curry powder	5	0	0.79	[0.13-1.8]	0.79	[0.13-1.8]	0	7.0	[2.7-14]	7.0	[2.8-14]	0	11	[5.2-23]	12	[5.7-23]

* Rounded to 2 significant figures