Article title: Polycyclic Aromatic Hydrocarbons (PAHs) Food Contamination: A contributing Factor to Rising Carcinogenicity

Authors: Joseph Luper Tsenum[1], Baturh Yarkwan[2]

Affiliations: Phystech School of Biological and Medical Physics, Moscow Institute of Physics and Technology (National Research University), Dolgoprudny, Moscow Region, Russian Federation[1], University of Agriculture Makurdi, Benue State-Nigeria[2]

Orcid ids: 0000-0002-1526-1305[1]

Contact e-mail: tsenumjosephluper@gmail.com

License information: This work has been published open access under Creative Commons Attribution License <http://creativecommons.org/licenses/by/4.0/>, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. Conditions, terms of use and publishing policy can be found at <https://www.scienceopen.com/>.

Preprint statement: This article is a preprint and has not been peer-reviewed, under consideration and submitted to ScienceOpen Preprints for open peer review.

Funder: Self

DOI: 10.14293/S2199-1006.1.SOR-PPRO2AU.v1

Preprint first posted online: 29 October 2020

Keywords: Polycyclic Aromatic Hydrocarbons (PAHs), Food, Occurrence, Exposure, Toxicity, Cancer

SUMMARY

Polycyclic aromatic hydrocarbons (PAHs) constitute a large class of organic compounds that are composed of two or more fused aromatic rings. They are primarily formed by incomplete combustion or pyrolysis of organic matter and during various industrial processes.

PAHs generally occur in complex mixtures which may consist of hundreds of compounds (Abou-Arab *et al.*, 2002).

Human absorption of PAHs follows different routes. While for non-smokers the major route of exposure is consumption of food, for smokers the contribution from smoking may be significant. Food can be contaminated from environmental sources that are present in air, soil or water, by industrial food processing methods (e.g heating, drying, and smoking) and by home food preparation (e.g grilling and roasting).

The Scientific Committee on food SCF (2005) reported that 15 priority PAHs out of the 33 PAHs which were considered in their assessment showed a clear evidence of mutagenicity/genotoxicity in somatic cells in experimental animals *in vivo* and with the exception of benzo(ghi)perylene also showed clear carcinogenic effects in various types of bioassays in experimental animals.

Thus, SCF (2005) conclusively reported that these compounds may be regarded as potentially genotoxic and carcinogenic to humans and thus represent a priority group in the assessment of the risk of long-term adverse health effects following intake of PAHs.

Key words: Polycyclic aromatic hydrocarbons (PAHs), Food, Occurrence, Exposure, Toxicity, Cancer.

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) constitute a large class of organic compounds that are composed of two or more fused aromatic rings. They solely consist of carbon and hydrogen and do not contain heteroatoms. PAHs are primarily formed by incomplete combustion or pyrolysis of organic matter and during various industrial processes, SCF (2005). Consequently, PAHs natural and anthropogenic sources in the environment are numerous. PAHs generally occur in complex mixtures which may consist of hundreds of compounds (Abou-Arab *et al.*, 2002). The composition of these mixtures varies with the generating processes. Humans are exposed to PAHs through various routes. While for non-smokers the major route of exposure is consumption of contaminated foods for smokers the contribution from smoking may be significant. Food can be contaminated from environmental sources, industrial food processing and from certain processes employed in home food preparation SCF (2005).

In the past decade, PAHs were evaluated by the international programme on chemical safety (IPCS), (WHO/IPCS, 1998), the scientific committee on food (SCF) (EC, 2002) and by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (FAO/WHO, 2005) wherein most recent PAHs reference material was evaluated by SCF (2005). It was concluded that 15 out of the 33 PAHs which were considered in their assessment, namely benz(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, benzo(a)pyrene, chrysene, cylopenta(cd)pyrene, indeno(1,2,3-cd)pyrene and 5-methylchrysene showed clear evidence of mutagenicity/genotoxicity in somatic cells as evident in experimental animals *in vivo*. With the exception of benzo(ghi)

perylene, the rest showed clear carcinogenic effects in various types of bioassays in experimental animals.

SCF (2005) concluded that these compounds may be regarded as potentially genotoxic and carcinogenic to humans and thus represent a priority group in the assessment of the risk of long-term adverse health effects following dietary intake of PAHs. Thus, by the expert committees' report (SCF, 2005), PAHs are clearly food contaminant that predisposes humans to an array of cancers.

LITERATURE REVIEW

1. Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) form a class of diverse organic compounds, each of them containing two or more fused aromatic rings. Hundreds of different such compounds may be formed and released during a variety of incomplete combustion and pyrolysis processes and thus the natural and anthropogenic sources of PAHs in the environment are numerous, EC (2005). PAH compounds are emitted from the processing of coal, crude oil, petroleum, and natural gas. Other sources are production of aluminium, iron and steel, from heating in power plants and homes (oil, gas, charcoal-fired stoves, wood stoves), burning of refuse, wood fires and from motor vehicle exhausts (Mottier *et al.*, 2000).

Humans can be exposed to PAHs through different routes. For the general population, it has been reported that, the major sources of exposure are from contaminated foods and inhaled air, while in smokers, the contributions from smoking and food may be of a similar magnitude. Foods can be contaminated by environmental PAHs that are present in air, soil or water or by industrial food processing methods (e.g. heating, drying and smoking) and by methods employed in home food preparations (e.g. grilling and roasting).

1.1 Properties/Structures of polycyclic aromatic hydrocarbons (PAHs)

The movement of PAHs in the environment depends on properties such as solution in water, and how easily they evaporate into the air (Abou-Arab *et al.*, 2002).

PAHs in general do not easily dissolve in water. They are present in air as vapors or stuck to the surfaces of small solid particles. According to ATSDR (1995), PAHs travel distances before they return to earth in rainfall or particle settling.

Table 1: Polycyclic aromatic hydrocarbons considered in the present opinion.

Compound	Abbr.	MW	CAS	Structure
<u>Benz[a]anthracene</u>	BaA	228.3	56-55-3
<u>Benzo[b]fluoranthene</u>	BbFA	252.3	205-99-2
<u>Benzo[j]fluoranthene</u>	BjFA	252.3	205-82-3
<u>Benzo[k]fluoranthene</u>	BkFA	252.3	207-08-9
<u>Benzo[ghi]perylene</u>	BghiP	276.3	191-24-2
<u>Benzo[a]pyrene</u>	BaP	252.3	50-32-8

Chrysene

CHR 228.3 218-01-9

Cyclopenta[cd]pyrene

CPP 226.3 27208-37-3

Dibenz[a,h]anthracene

DBahA 278.3 53-70-3

Dibenzo[a,e]pyrene

DBaeP 302.3 192-65-4

Dibenzo[a,h]pyrene

DBahP 302.3 189-64-0

Dibenzo[a,i]pyrene

DBaiP 302.3 189-55-9

Dibenzo[a,h]pyrene	DBaP	302.3	191-30-0
<u>Indeno[1,2,3-cd]pyrene</u>	IP	276.3	193-39-5
5-methylchrysene	MCH	242.3	3697-24-3
Benzo[c]fluorene	BcFL	216.3	205-12-9

Abbr.: Abbreviation, MW: Molecular weight, CAS: Chemical Abstract Service Number

1.2. Occurrence/Pollution of polycyclic aromatic hydrocarbons (PAHs)

Over 100 PAHs have been identified and occur as complex mixtures, not as individual component, EC (2005).

PAHs comprise the largest class of known chemical carcinogens and have been detected in the environment especially in air, water, soil and foods (Abou-Arab *et al.*, 2002). These carcinogens enter the environment mostly as releases to air from volcanoes, forest fires, and residential wood burning, cigarette smoke, asphalt roads, coal, coal tar, agricultural burning, municipal and industrial waste incinerations, hazardous waste sites and exhaust from automobiles and trucks (Mottier *et al.*, 2000). ATSDR (1995) reported that these carcinogens can also enter the surface water through discharges from industrial plants and waste water treatment

plants which can be released to soils at hazardous waste sites if they escape from storage containers.

Clinical studies have shown that human exposure to a mixture of highly concentrated PAHs may cause various cancers, in skin, lung, stomach and liver.

1.3. Detection of polycyclic aromatic hydrocarbons (PAHs)

PAHs can be detected in the environment especially in air, water, soil and foods.

Nowadays, the two main analytical techniques for determining PAHs in foods are high performance liquid chromatography (HPLC) coupled to a fluorescence detector (FLD) and gas chromatography-mass spectrometry (GC-MS) (Van der Wielen *et al.*, 2006; ISO, 2007). Both of these methods are sufficiently sensitive for determining PAH concentrations usually found in foods (Van der Wielen, *et al.*, 2006; Varlet *et al.*, 2007; Veyrand *et al.*, 2007).

1.4. Polycyclic aromatic hydrocarbons (PAHs) Toxicity and Human Health

Polycyclic aromatic hydrocarbons (PAHs) are proven animal carcinogens, mutagens and are teratogenic to humans, EC (2005). They cause cancer, mutation and are known to be teratogenic in humans, US EPA (1986). Clinical studies have shown that human exposure to a mixture of highly concentrated PAHs may cause various cancers, in skin, lung, stomach and liver. It has also been proven that PAHs are responsible for the increasing cancer risks as PAHs are capable of damaging genetic materials and thus initiating the development of cancers (Schneider, *et al.*, 2004).

1.5. Sources of Food Contamination

Environmental pollution in different countries is becoming a serious problem, it is possible that PAHs may be widely distributed in the environment and then contaminates food, SCF (2005).

PAHs have been found in food products, fresh vegetables, fruits, and cereals, contaminated waters, animal products (Kang *et al.*, 2003), milk and fat (Grova *et al.*, 2001), meat, SCF (2002). Other sources are vegetable oils and margarine (Thomson *et al.*, 1996), smoked fish, smoked meats, processed cereal based foods, EC (2005) etc. The European Food Safety Authority (EFSA, 2008) reported that in aqueous environments, PAHs are generally found absorbed on particulates and on humic matter, or dissolved in any oily contaminant present in water, sediments and soil.

EFSA(2008) has it that PAHs can also contaminate foods during industrial smoking, heating and drying processes that allow combustion products to come into direct contact with food.

Contamination of cereals and vegetable oils (including seed oils and olive residue oils) with PAHs usually occur during technological processes like direct fire drying, where combustion products may come into contact with the grain, oil seeds or the oil (Speer *et al.*, 1990; EC, 2001).

Furthermore, PAHs are formed as a result of certain home food preparation methods, such as grilling, roasting and smoking.

High PAH concentrations have been reported in charcoal grilled/barbecued foods (such as fatty meat and meat products grilled under prolonged and severe conditions), in foods smoked by traditional

techniques (fish in particular), and in mussels and other seafood from polluted water (Guillen *et al.*, 1997; pillips *et al.*, 1999).

Smoked and grilled food may contribute significantly to the intake of PAHs if such foods are a large part of the usual diet (Guillen, *et al.*, 2000). The presence of PAHs in coffee has been suspected to be due to either a contamination of green coffee beans during drying or an endogenous formation in the coffee beans during the roasting process (Houessou, *et al.*, 2005; Houessou, *et al.*, 2008).

1.6. Occurrence and Patterns of polycyclic aromatic hydrocarbons (PAHs) in Food

PAHs generally occur in food as complex mixtures, IPCS (2008). SCF(2008) evaluated and reported that 15 PAHs are known to be found in food, namely benz(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, benzo(a)pyrene, chrysene, cyclopenta(cd)pyrene, dibenz(a,h)anthracene, dibenzo(a,e)pyrene, dibenzo(a,h)pyrene, dibenzo(a,i)pyrene, dibenzo(a,l)pyrene, indeno(1,2,3 cd)pyrene and 5-methylchrysene showed clear evidence of mutagenicity/genotoxicity in somatic cells in experimental animals in vivo and with the exception of benzo(ghi)perylene have also showed clear carcinogenic effects in various types of bioassays in experimental animals.

1.7. Factors Influencing the Levels of PAHs in Food.

There is a variety of literature on the factors that influence the levels of PAHs in food due to commercial or home cooking processing techniques. The following summary gives a short overview of the key findings.

1.7.1. Commercial Processing Techniques

Traditional commercial smoking techniques, in which smokes from incomplete wood burning comes into direct contact with the food, can lead to its considerable contamination with various PAHs if the process is not adequately controlled, EFSA (2008). Critical parameters include temperature, time, humidity, types of control and smoke used (natural or generated), and the design and types of smoke houses or kilns. EC (2005) suggested that modern smokehouses or kilns control the air-flow mechanically and electrically and generally have temperature monitors and controls, and microprocessor control systems that can regulate smoke exposure, humidity, drying, and temperature. This permits strict control of the complex smoking operation. Wood smoke can be generated by burning wood or more commonly, by heating sawdust or small wood chips.

A wide variety of woods have been used for smoking, including oak, hickory, mahogany, pine, whitewood, cherry, apple, alder, mesquite, beech birch, and maple to impart various flavor and colors. However, of all those types of wood, soft woods emit more PAHs than hard wood (Jahncke, *et al.*, 2001).

1.7.2. Home Cooking and Other Small Cooking Practices.

EFSA (2008) reported that the type of food processing may have a significant influence on the PAH levels in food commodities. The increasing replacement of traditional smoking processes by liquid smoke flavoring has certainly led to a decrease of PAH levels in commercially smoked food commodities. On the other hand, a number of investigations, especially on various barbecuing practices have demonstrated that certain home cooking practices may lead to PAH levels that are more than one magnitude higher compared to PAH concentrations in foods prepared with proper practices, EC(2008). Thus, a considerable potential for a reduced formation of PAHs and consequently for lowering the exposure to these compounds seems feasible for certain home cooking practices if techniques that avoid the pyrolysis of fat that drops into the flames are applied. The effects of frying, grilling, barbecuing, toasting and roasting on the formation of PAHs in foods prepared in the home and from catering outlets have little evidence of PAH formation during the grilling, frying, roasting and toasting experiments as investigated (White, *et al.*, 2008).

1.7.3. Food Consumption.

The level of contaminated food with PAHs can cause a rise in PAH concentrations in the body when consumed, thereby increasing carcinogenicity, EFSA (2008).

1.8. Absorption of PAHs in Food.

Absorption of PAHs from diet is determined by the size and lipophilicity of the molecule, the presence of bile in the digestive tract, the dose ingested and lipid content of the diet (Laher, *et al.*, 1987; ATSDR, 1995). In humans, indirect evidence for the gastrointestinal absorption of PAHs have been detected in the urine, the metabolite 1-hydroxypyrene, following ingestion of diets containing very low levels of benzo(a)pyrene (Buckley, *et al.*, 1992).

1.9. Distribution of PAHs in the Body.

WHO/IPCS (1998, 2007) reported that PAHs are widely distributed in maternal tissues and in fetuses, showing that they can cross the placenta. PAH compounds or their metabolites can cross the blood-brain barrier (Lipniak, *et al.*, 1993).

2. Metabolism of PAHs in the body.

PAHs with planar aromatic structures require metabolic activation for their toxic, mutagenic and carcinogenic action (Harvey, *et al.*, 1991; Xue *et al.*, 2005). Furthermore, in most cases cytochrome p450 (CYP) catalyzed epoxide formation is an initial step in the PAHs activation process, followed by formation of other highly reactive electrophilic metabolites capable of binding to cellular macromolecules, in particular proteins and nucleic acids (Agundez *et al.*, 2004; Xue *et al.*, 2005).

2.1. Excretion of PAHs.

After initial metabolism, most of the detoxified portion of PAH compounds are excreted into the bile as metabolites, then subsequently eliminated in the feces, EC (2005). A small proportion is excreted in urine and can be excreted into the intestine via the bile, reabsorption, and return to the liver by the portal circulation (enterohepatic recirculation) (Ramesh, *et al.*, 2004).

2.2. Biomarkers of Exposure.

The most prominent biomarker of exposure to PAHs in humans is the level of one or more PAH metabolites in urine (Scherer, *et al.*, 2000; Yang, *et al.*, 2003). 1-Hydroxypyrene, hydroxynaphthalenes and hydroxyphenanthrenes are the PAH metabolites most widely accepted as reliable biomarkers of internal PAH exposure because they are excreted in urine at substantial extent, making possible their monitoring by analytical methods currently available (Foster, *et al.*, 2008).

2.3. Etiology of Cancer.

Cancer is so called a disease because swollen veins around the area, resembles a crab's limbs. The international union against cancer (UICC) has defined cancer as a disturbance of growth characterized by excessive proliferation of cells without apparent relation to the physiological demands of the organs involved. All cancers are multifactorial in origin. They include genetic, hormonal, metabolic, physical, chemical and environmental factors. All cancers originate usually from one aberrant cell, which goes onto multiply and produce a tumor mass. The immune

system surveillances remove and destroy the aberrant cells. Thus, with advances in age, the number of mutation accumulate, hence they increased statistical probability of the incidence of cancer. Cancer is a second most common cause for death in developed countries, WHO (2013).

2.3.1. PAHs as Carcinogens

PAHs as carcinogens are known to excessively proliferate cells without apparent relation to the physiological demands of the organs involved, thereby destroying them and causing cancer. At this end, PAHs food contamination is a strong contributing factor to rising carcinogenicity.

2.3.2. Management/Prevention of Cancer and Food Contamination.

At least one-third of all cancer causes are preventable. Prevention offers the most cost- effective long-term strategy for the control of cancer. WHO (2013).

Cancer can be prevented by dietary modification, reduction in the consumption of red and preserved meat, healthy eating habits, regular physical activity and the maintenance of a healthy body weight, along with a healthy diet.

National policies and programmers' should also be implemented to raise the awareness and reduce exposure to cancer risk factors, and to ensure that people are provided with the information and support they need to adopt healthy lifestyles.

Other preventive measures are reduction in alcohol consumption, low or no exposure to environmental chemical pollutants, no tobacco smoking, chewing and snuffing.

Modern smokehouses or kilns control the air flow mechanically and electrically and generally have temperature monitors and controls, and microprocessor control systems that can regulate smoke exposure, humidity, drying, and temperature. Thus, permits strict control of the complex smoking operation (Jahncke, *et al.*, 2001).

CONCLUSION

In conclusion, PAHs (an unnoticed foe in our environment) causes cancer in both animals and humans upon exposure to PAH contaminated foods, wood smoke etc. through oral absorption, gastrointestinal absorption, venous system absorption etc. The type of food processing/preservation methods (smoking, drying, grilling etc.) have a significant influence on the PAH levels in food commodities. Modern methods of food processing/preservation should be used to reduce the high levels of PAHs in food commodities.

National policies and programmers' should also be implemented to raise the awareness and reduce exposure to cancer risk factors, and to ensure that people are provided with the information and support they need to adopt healthy lifestyles.

RECOMMENDATIONS

- Toxicological data for the individual carcinogenic PAHs as well as oral carcinogenicity data with mixtures relevant for dietary exposures should be developed.
- Additional carcinogenicity and occurrence data for benzo(c)fluorene are needed.
- A survey of commonly concerned foods and their extent of PAHs contamination to avoid undue human exposures.

REFERENCES

1. Abou-Arab, A.A.K.(2002). Degradation of organochlorine pesticides by meat starter in liquid media and fermented sausage. *Food and Chemical Toxicology*, 40, 33-41.
2. Agundez, J.A. 2004. Cytochrome P450 gene polymorphism and cancer. *Curr. Drug Metab.* 5:211-224.
3. ATSDR (1995). Agency for Toxic Substances and Disease Registry. Toxicological profile for polycyclic aromatic hydrocarbons (PAHs). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.
4. Buckley, T.J. and Lioy, P.J. 1992. An examination of the time course from human dietary exposure to polycyclic aromatic hydrocarbon to urinary elimination of 1-hydroxypyrene. *Br.J. Ind. Med.* 49: 113–124.
5. EC (European Commission). 2001. Outcome of the expert group meeting on 3 October on ways.
6. EC (European Commission). 2002. Opinion of the Scientific Committee on Food on the risks to human health of Polycyclic Aromatic Hydrocarbons in food to prevent contamination of olive residue oil and other oils with polycyclic aromatic hydrocarbons (PAH). Summary record of the 85th meeting of the Standing Committee on Foodstuffs, 25th October 2001, agenda item 9.

7. EFSA (European Food Safety Authority). 2008. Guidance Document for the Use of the Concise.
8. FAO/WHO (Food and Agriculture Organization of the United Nations/World Health Organization). 2005. Joint FAO/WHO Expert Committee on Food Additives (JECFA). Sixty fourth meeting, Rome, 8-17 February 2005. Summary and Conclusions.
9. Forster, Preuss, R., Ross bach, B., Brunning, T., Angerer, J. and Simon, P. 2008. 3-Hydroxybenzo(a)pyrene in the urine of workers with occupational exposure to polycyclic aromatic hydrocarbons in different industries, *Occup. Environ. Med.* 65:224-229.
10. Grova, N.; Feidt, C.; Crepineau, C.; Laurent, C.; Lafargue, P.E.; Hachimi, A. and Rychen, G.O (2001). Detection of polycyclic aromatic hydrocarbon levels in milk collected near potential contamination sources. *J. Agric. Food Chem.*, 50, 4640-4642.
11. Guillén, M.D., Sopelana, P. and Partearroyo, M.A. 2000. Determination of polycyclic aromatic hydrocarbons in commercial liquid smoke flavorings of different compositions by gas chromatography-mass spectrometry. *J. Agric. Food Chem.* 48: 126-131.
12. Guillén, M.D., Sopelana, P., and Partearroyo, M.A. 1997. Food as a source of polycyclic aromatic carcinogens. *Rev. Environ. Health*, 12: 133-146.
13. Harvey, R.G. 1991. Polycyclic aromatic hydrocarbons, Chemistry and Carcinogenicity. Cambridge University Press, Cambridge, UK, pp. 11-87.

14. Houessou, J.K., Benac, C., Delteil, C. and Camel, V. 2005. Determination of polycyclic aromatic hydrocarbons in coffee brew using solid-phase extraction. *J. Agric. Food Chem.* 53: 871-879. Polycyclic Aromatic Hydrocarbons in Food.
15. Houessou, J.K., Goujot, D., Heyd, B. and Camel, V. 2008. Modeling the formation of some polycyclic aromatic hydrocarbons during the roasting of *Arabica* Coffee samples. *J. Agric. Food Chem.* 56: 3648-3656.
16. ISO (International Organization for Standardization). 2007. Animal and vegetable fats and oils –Determination of polycyclic aromatic hydrocarbons by on-line donor acceptor complex chromatography and HPLC with fluorescence detection. Draft International Standard ISO/DIS 22959. ISO/TC 34/SC 11.
17. Jahncke, M.L. and Herman, D. 2001. Control of food safety hazards during cold-smoked fish processing. *J. Food Sci. – Supplement to Vol.* 66(7): S1104-S1112.
18. Kang, H.G., Jeong, S.H., Cho, M.H., and Cho, J.H. 2003. Changes of biomarkers with oral exposure to benzo(a)pyrene, phenanthrene and pyrene in rats. *J. Vet. Sci.* 8: 361-368.
19. Laher, J. M. and Barrowman, J. A. 1987. Intestinal absorption of carcinogenic hydrocarbons. *Ann. N. Y. Acad. Sci.* 534:565-574.

- 20.Lipniak, M. and Brandys, J. 1993. Toxicokinetics of fluoranthene, pyrene and benz(a)anthracene in the rat. *Polycyclic Aromatic Compounds*. 3: 111-119.
- 21.Mottier, P.; Parisod, V. and Turesky, R.J.(2000). Quantitative determination of polycyclic aromatic hydrocarbons in barbecued meat sausages by gas chromatography coupled to mass spectrometry. *J. Agric. Food Chem.*, 48:1160-1166.
- 22.Phillips, D.H. 1999. Polycyclic Aromatic Hydrocarbons in the Diet.*Mutat.Res.*, 443: 139- 147.
- 23.Ramesh, A., Walker, S.A., Hood, D.B., Guillén, M.D., Schneider, K. and Weyand, E.H. 2004.Bioavailability and risk assessment of orally ingested polycyclic aromatic hydrocarbons. *Int.J. Toxicol.* 23: 301-333.
- 24.SCF (2008). Scientific Committee on Foods of EC. Opinion of the Scientific Committee on Food in the risk to human health of PAHs in food. Brussels: SCF.
- 25.Scherer, G., Frank, S., Riedel, K., Meger-Kossien, I. and Renner, T. 2000. Biomonitoring of exposure to polycyclic aromatic hydrocarbons of non-occupationally exposed persons. *Cancer epidemiol. Biomark. Prev.* 9:373-380.
- 26.Schneider, K., Roller, R., Kalberlah, F. and Schuhmacher-Wolz, U. 2004. Cancer risk assessment for oral exposure to PAH mixtures. *J. Appl. Toxicol.* 22: 73-83.

27. Speer, K., Steeg, E., Horstmann, P., Kühn, T. and Montag, A. 1990. Determination and distribution of polycyclic aromatic hydrocarbons in native vegetable oils, smoked fish products, mussels and oysters, and bream from the river Elbe. *J. High Res. Chrom.*, 13: 104-111.
28. Thomson, B.; Lake, R. and Lill, R. (1996). The contribution of margarine to cancer risk from polycyclic aromatic hydrocarbons in the New Zealand diet. *Polycyclic aromatic compounds*, 11, 177-184.
29. US EPA (United States, Environmental Protection Agency). 1986. Guidance for health risk from.
30. Van der Wielen, J.C.A., Jansen J.T.A., Martena, M.J., De Groot, H.N. and In't Veld, P.H. 2006. Determination of the level of benzo[*a*]pyrene in fatty foods and food supplements. *Food Addit. Contam.* 23(7): 709-714.
31. Varlet, V., Serot, T., Monteau, F., Le Bizec, B. and Prost, C. 2007. Determination of PAH profile by GC-MS/MS in salmon by processed by four cold-smoking techniques. *Food Addit. Contam.* 24(7): 744-757.
32. Veyrand, B., Brosseaud, A., Sarcher, L., Varlet, V., Monteau, F., Marchand, P., Andre, F. and LeBizec, B. 2007. Innovative method for determination of 19 polycyclic aromatic hydrocarbons in food and oil samples using gas chromatography coupled to tandem mass spectrometry based on an isotope dilution approach. *J. Chromatogr. A*: 1149: 333-344.
33. White, S., Fernandes, A. and Rose, M. 2008. Investigation of the formation of PAHs in foods prepared in the home and from catering outlets to determine the effects of frying, grilling, barbecuing, toasting

and roasting. FD 06/13.) Food Standard Agency (FSA)/Central Science Laboratory (CSL).

34. WHO/IPCS (World Health Organization/International Programme on Chemical Safety). 2007. Draft guidance document on characterizing and communicating uncertainty in exposure assessment.
35. WHO/IPCS (World Health Organization/International Programme on Chemical Safety). 1998. Selected Non-heterocyclic Polycyclic Aromatic Hydrocarbons. Environmental Health Criteria. International Programme on Chemical Safety, World Health Organization, Geneva.
36. Xue, W. and Warschawsky, D. 2005. Metabolic activation of polycyclic and heterocyclic aromatic hydrocarbons and DNA damage: A review. *Toxicol. Appl. Pharmacol.* 206: 73-93.
37. Yang, M., Kim, S., Lee, E., Cheong, H.K., Chang, S.S., Kang, D., Choi, Y., Lee, S.M. and Janh, J.Y. 2003. Sources of polycyclic aromatic hydrocarbon exposure in non-occupationally exposed Koreans. *Environ. Mol. Mutagen.* 42: 250.