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Agenda Item 9

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**JOINT FAO/WHO FOOD STANDARDS PROGRAMME
CODEX COMMITTEE ON CONTAMINANTS IN FOODS**

Second Session

The Hague, The Netherlands, 31 March - 4 April 2008

**PROPOSED DRAFT CODE OF PRACTICE FOR THE REDUCTION OF CONTAMINATION OF
FOOD WITH POLYCYCLIC AROMATIC HYDROCARBONS (PAH) FROM SMOKING AND
DIRECT DRYING PROCESSES**

(N07-2006)

(At Step 3 of the Elaboration Procedure)

Governments and international organizations are invited to submit comments on the following subject matters no later than 14 March 2008, preferably in electronic format, for the attention of Ms. Tanja Åkesson, the Netherlands Secretariat of the Codex Committee on Contaminants in Foods, Fax No.: +31 70 3786141; E-mail: info@codexalimentarius.nl with a copy to the Secretary, Codex Alimentarius Commission, Joint FAO/WHO Food Standards Programme, Viale delle Terme di Caracalla, 00153 Rome, Italy (Fax +39.06.5705.4593; E-mail: Codex@fao.org).

BACKGROUND

1. The Codex Committee on Food Additives and Contaminants, at its 38th Session (April 2006), agreed to start new work to elaborate a proposed draft Code of Practice for the reduction of contamination of food with Polycyclic Aromatic Hydrocarbons (PAH) from smoking and direct drying processes and agreed to establish an electronic working group for preparing an initial draft, for circulation, comments at Step 3 and consideration at Step 4 at the First Session of the Codex Committee on Contaminants in Foods (CCCF) (ALINORM 06/29/12 Para. 188). This initiative was based on a discussion paper from the delegation of Denmark and a project document for submission to the Codex Alimentarius Commission (CAC) to develop a Code of Practice for reduction of the contamination of food with polycyclic aromatic hydrocarbons (PAH) during food processing.
2. The new work proposal was approved by the 29th Session of the Codex Alimentarius Commission (July 2006) as N06-2006 (ALINORM 06/29/41, Appendix VIII)
3. Furthermore, the substances had been assessed by Joint Expert Committee on Food Additives (JECFA). JECFA assessed PAH at its sixty-fourth meeting in February 2005 and concluded that the critical effect of PAH is carcinogenicity and as some PAH are genotoxic. It was not possible to assume a threshold mechanism or to establish a provisional tolerable weekly intake (PTWI). JECFA concluded that the estimated intakes of PAH were of low concern for human health in the case of normal dietary intake, but stated that efforts should be made to reduce contamination with PAH during drying and smoking processes (WHO 2006).

4. The CCCF, at its First Session, discussed the Proposed Draft Code of Practice for the Reduction of Contamination of Foods with Polycyclic Aromatic Hydrocarbons (PAH) from Smoking and Direct Drying Processes and agreed to return it to Step 2 for redrafting by an electronic working group led by Denmark, with a view to circulation for comments at Step 3 and consideration at Step 3 at the Second Session of the CCCF (ALINORM 07/30/41 paragraph 102).

REPORT OF THE ELECTRONIC WORKING GROUP

5. As agreed by the CCCF at its First Session, the electronic working group led by Denmark redrafted the Proposed Draft Code of Practice for the Reduction of Contamination of Foods with Polycyclic Aromatic Hydrocarbons (PAH) from Smoking and Direct Drying Processes, which is presented in ANNEX I to this document.

6. Australia, Austria, Belgium, Cuba, EU, France, Germany, Ghana, Italy, Japan, the Netherlands, Nigeria, Philippines, Poland, Republic of Korea, South Africa, Spain, Thailand, the United Kingdom, the United States of America and CPA (Alliance des pays Producteur de Cacao) participated in the electronic working group. A list of the participants is presented in ANNEX II to this document.

7. The re-drafted version took into account comments received before and during the First Session of the CCCF. In the process of redrafting, it included comments received from Ghana, Latvia, Germany, Sweden, France, European Union (EU) together with comments given during the First Session of the CCCF. The redrafted document was sent to the participants of the electronic working group in November 2007 for commenting. Comments were received from Cuba, EC, Japan, the Netherlands, Nigeria and Thailand.

8. The electronic working group prioritised the discussion of the structure of this Code of Practice, a matter of principles, and several comments expressed the general opinion, that all the Codex Code of Practices should have the same structures. However, the existing Code of Practice does not have a uniform structure, but the structure of this draft is having a structure of an average of Code of Practice's from the different Codex committees.

9. The Code of Practice is being developed as a means of disseminating strategies that will facilitate the reduction of PAH in internationally traded foodstuffs. The Code of Practice discusses those established minimization techniques that have been demonstrated to be effective according to literature and in a commercial setting.

10. The focus of this Code of Practice is solely on foods produced by smoking or direct drying processes. It describes some critical control points in Good Manufacturing Practices and how evaluation of the potential contamination of the food with PAH could reduce the formation of PAH coupled with the choice of processes.

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INTRODUCTION

1. Many chemical contaminants are formed during the combustion of fuel both in the smoking and in the direct drying process. Examples include polycyclic aromatic hydrocarbons (PAH), dioxins, formaldehyde, nitrogen and sulfur oxides (relevant for formation of e.g. nitrosamines). Furthermore, heavy metals are also found in combustion gases. The types and amount depend on the fuel used, the temperature and possible other parameters (Nielsen and Illerup, 2003).

2. This Code of Practice (COP) covers contamination of food with PAH from smoking and direct drying, only. PAH are chemical contaminants, which can be found in food. A list of PAH included in the JECFA assessment is found in Appendix I.

3. Sources of PAH are contamination during food processing or the environment. PAH may be formed during food processing in both commercial and domestic food preparation, notably:

- Smoking,
- Drying,
- Cooking (Roasting, baking, frying and barbecuing).

Furthermore, PAH can also be present in the raw materials due to environmental contamination.

4. Contamination of food with PAH via environmental contamination should be controlled either by source-directed measures like filtering the smoke from relevant industries (e.g., cement work, incinerator and metallurgy) and limiting the exhaust of PAH from cars. Good agricultural practices (GAPs), including the selection of appropriate farmland, could also decrease the environmental contamination of foods with PAH. Harvesting of shellfish from contaminated water should be avoided. However, this contribution to the PAH intake from the food is not included in this COP.

5. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) conducted a comprehensive risk assessment of PAH in 2005 (WHO 2006). JECFA recommended keeping the content of these contaminants in food as low as reasonably achievable. Toxicological information is included in Appendix II. In EU, benzo[*a*]pyrene is used as a marker for the occurrence of PAH in food; however, the suitability of benzo[*a*]pyrene is currently under review by the European Food Safety Authority.

6. In its opinion on PAH, JECFA recommended that efforts should be made to reduce contamination with PAH during drying and smoking processes, e.g. by replacing direct smoking (with smoke developed in the smoking chamber, traditionally in smokehouses) with indirect smoking (JECFA, WHO, 2006).

7. The PAH content of thermally treated food differs depending on the processes used and how they are conducted. Occurrence data from the JECFA monograph (WHO 2006), in the EU SCOOP report (European Commission, 2004) and some national studies are found in Appendix III.

8. From the data reviewed by the EU Scientific Committee on Food (SCF) (now the European Food Safety Authority (EFSA)), cereals, vegetables, fats and oils were the major contributors to PAH in the diet, with grilled/smoked /barbecued fish and meat making a relatively low contribution except in cultures where they are a significant part of the diet (European Commission, 2002). However, grilled/smoked/barbecued fish and meat can contribute significantly to the intake of PAH where such foods are the usual part of the diet. For example, grilled/barbecued meat was the second highest contributor, after the “bread, cereal and grain” group, in a study in the U.S. (*reference needed from the US*). With respect to the relative contribution of fats and oils, one recent study (COT, 2002) showed that these foods contribute far less to PAH intake in the UK diet than previously shown (Dennis et al., 1983): 6 % versus 59 % for benzo[*a*]pyrene, and 3 % versus 34 % for total PAH.

OBJECTIVES

9. The objective of this COP is to identify critical point of importance for a reduction of contamination of food with PAH during commercial smoking and direct drying processes.

10. The COP is intended to provide tools to optimise smoking and drying processes in order to reduce or eliminate PAH in the final foodstuffs. The COP must recognise the benefits of smoking and drying including the availability of traditional smoked food products, prevention of degradation and microbiological contamination and growth and the potential for lowering the risks to human health from PAH formed in foods during processing.

SCOPE

11. The scope of this COP is PAH contamination during commercial smoking, both direct and indirect and direct drying processes.

12. The COP does not cover PAH contamination in food originating from

- a. Use of herbs and spices in the smoking process¹
- b. Other food processes, including barbecuing and other types of cooking in private homes or the catering sector
- c. Environmental contamination
- d. Drinking water.

13. This COP covers contamination with PAH only. It should, however, be emphasized that conditions that lead to a reduction of one contaminant might lead to increases in the levels of other contaminants or could lower the microbiological standard of the products. The possible interplay among levels of contaminants like PAH, heterocyclic amines, and nitrosamines is not always well understood, but these contaminants can be food safety problems either as such or due to the reaction of e.g., nitrogen oxide with components in the food leading to the formation of nitrosamines. It should be underlined that any guidance given to minimize PAH should not lead to increase in other contaminants.

14. Furthermore, in relation to contaminants like mycotoxins, it is recommended not to have direct drying on the ground of figs, ground etc. in order to avoid formation of mycotoxins. These aspects are not considered in this code of practice.

DEFINITIONS

15. *Contaminant* is defined as “Any substance not intentionally added to food, which is present in such food as a result of the production (including operations carried out in crop husbandry, animal husbandry and veterinary medicine), manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food or as a result of environmental contamination. The term does not include insect fragments, rodent hairs and other extraneous matter.” (Codex Alimentarius, Procedural Manual, 14th edition 2004).

16. *Drinking water* is water that meets the quality standards of drinking water described in the WHO Guidelines for Drinking Water quality.

17. *Drying* can take place either as *direct drying* or *indirect drying*.

18. *Drying, direct* is a drying process where the combustion gas is used directly as the drying gas in contact with the food, and in indirect drying, the drying gas is heated via a heat exchanger, electricity or by other means. The direct drying process can be drying in the sun or by using combustion gases.

19. *Drying, indirect* is a drying process where the combustion gas is in a closed system and not coming into direct contact with the foods. As indirect drying is not regarded as a significant source of PAH, it is not covered by the COP and will not be addressed in this COP.

¹ In the *traditional smoking process*, the fuel used is often various wood species, in some cases with herbs and spices, e.g. juniper berries, to give a characteristic flavour. Such herbs and spices may be a potential source for PAH contamination. However, many different types of herbs and spices can be used, but normally only in smaller quantities and knowledge about the influence of using herbs and spices is limited. Their use is therefore not considered in this Code of Practice.

20. *Polycyclic aromatic hydrocarbons (PAH)* are a group of contaminants that constitute a large class of organic compounds containing two or more fused aromatic rings made up of carbon and hydrogen atoms. Hundreds of individual PAH may be formed and released as a result of incomplete combustion or pyrolysis of organic matter, during industrial processes or other human activities, including the processing and preparation of food and the carbonization of wood to make charcoal (WHO, 2006).
21. *Pyrolysis* is the chemical decomposition of organic materials by heating in the absence of oxygen or any other reagents, except possibly steam (http://en.wikipedia.org/wiki/Main_Page).
22. *Smoke* consists of liquid and solid particulates suspended in a gaseous phase. Particles in the smoke, generally of a size of 0.2-0.4 μm (or as low as 0.05 to 1 μm (Guillén et al., 2000)), are estimated to constitute 90% of its overall weight. The chemical composition of smoke is complex and more than 300 components have been identified (Möhler, K, 1978; Solttes and Elder, 1981; Simko, P, 2005).
23. *Smoking* of food is a process used as a preservation method use to prolong the shelf life of food due to components of the smoke inhibiting growth of some microorganisms. The smoking process is furthermore used to achieve the characteristic taste and appearance of smoked food.
24. *Smoking, direct* is the traditional type of smoking process, where the smoke is developed in the chamber in which the food is processed. Direct smoking requires less equipment than indirect smoking but can result in higher levels of PAH in the final food product.
25. *Smoking indirect* is a process where smoke generators are use, and the smoke is being developed in a chamber, separate from where the food is smoked. The smoke is possibly cleaned in various ways e.g. by use of a water filter or a tar condenser before being fed into the smoke chamber.
26. *Wood* is a solid material derived from woody plants, notably trees but also shrubs. Wood from the latter is only produced in small sizes, reducing the diversity of uses. In its most common meaning, "wood" is the secondary xylem of a woody plant, but this is an approximation only: in the wider sense, wood may refer to other materials and tissues with comparable properties (http://en.wikipedia.org/wiki/Main_Page). Wood consists of three main components: cellulose, hemicellulose and lignin (Andersen and Rissum, 1994) in a 2:1:1 ratio, and represent 95 % of dry matter. *Wood* is often divided into two groups: Hardwood and softwood. Generally, there is more hemicellulose in hardwoods than in softwoods and more lignin in conifers, which are covered by the group of softwoods.
27. *Wood, hardwood* is a term designates wood from broad-leaved (mostly deciduous, but not necessarily, in the case of tropical trees) or angiosperm trees. Hardwoods have broad leaves and enclosed nuts or seeds such as acorns. They often grow in subtropical regions like Africa and also in Europe and other regions such as Asia (<http://en.wikipedia.org/wiki/Hardwood>).
28. *Wood, softwood* is a term used for wood from conifer trees. On average, hardwood is of higher density and hardness than softwood, but there is considerable variation in actual wood hardness in both groups, with a large amount of overlap; some hardwoods (e.g. balsa) are softer than most softwood, while yew is an example of hard softwood. The dominant feature separating hardwoods from softwoods is the presence of pores, or vessels. Hardwood species are more varied than softwood. There are about a hundred times as many hardwood species as softwoods. The vessels may show considerable variation in size, shape of perforation plates (simple, scalariform, reticulate, foraminate), and structure of cell wall (e.g. spiral thickenings) (<http://en.wikipedia.org/wiki/Hardwood>).

PREVENTIVE MEASURES AND GENERAL CONDITIONS IN GOOD MANUFACTURING PROCESSING OF FOOD.

29. The food producer should carry out a hazard analysis of the critical control points (HACCP) in processes used or intended to be used in food production.
30. The hazard analysis of the critical control points should include assessment of the potential formation of process contaminants during the process and should address the following points:
- ⇒ Possible sources of contaminants such as PAH during the process
 - ⇒ Possible effects on consumer health
 - ⇒ Controllability
 - ⇒ Feasibility and effectiveness of controls (cost, commercial availability, occupational hazards)

In the COP for the smoking and drying process, critical points are highlighted in the flow sheets in appendix IV.

31. Other factors may also legitimately be considered, such as
 - ⇒ Required organoleptic properties of the final food product
 - ⇒ Effects of the processes on organoleptic properties and quality of the product (the ideal method would have no adverse effects on the appearance, odour, taste or nutritional properties of the product.)
 - ⇒ Consumer perception and choice
 - ⇒ Environmental impact of the smoking process.
32. Considerations should be made as to which process should be used and whether a less contaminating process is available.
33. The effect of any process options on the microbiological status of the food product is a critical control point, which should also be taken into account.

EVALUATION OF COMPLIANCE WITH RELEVANT LEGISLATION

34. Processed food shall be in compliance with relevant national or international legislation and standards, including general requirements for consumer protection.

SMOKING AND DRYING PROCESSES, GENERAL REMARKS

35. Traditional processes such as smoking and direct drying provide a wide variety of food textures and flavours and consequently a broader choice for consumers. Many types of smoked and dried foods are highly estimated traditional food items, where these types of processes have been used to prolong storage times and quality and provide flavour and consistency required by consumers. The extension of shelf life may also have an effect on the nutritional value of foodstuffs, such as the vitamin content.
36. The smoking and drying processes is used both in industry and in private households. Consumers might smoke food and would often use a direct process, while drying can be done either as direct or as indirect drying, e.g. in the sun or in a microwave oven. The COP and the guidance given is mainly directed to the industry, but could be used as the basis for information to consumers.
37. The formation of PAH during smoking and drying is dependent on a number of variables, including
 - a. Fuel (woods, diesel, gases, liquid/solid waste and other fuels)
 - b. Cooking method (smoking or drying - direct or indirect)
 - c. Smoke generation process (friction, smouldering, auto-combustion), thermostated plates or liquid smoke vaporisation and direct smoking).
 - d. The distance between the food and the heat source
 - e. Position of the food in relation to the heat source
 - f. Fat content of the food and what happens to it during processing
 - g. Duration of processing
 - h. Temperature during processing
 - i. Cleanliness and maintenance of equipment.
38. In general, changes in processing techniques can in some cases reduce the amount of PAH formed during processing and found in the processed food. Alteration of the process could be done in different ways after considerations of the critical points e.g. by using indirect drying or smoking processes instead of direct drying or smoking; via the selection of fuel for drying or of wood species used in the smoking process; and by adjusting times and processing temperatures. In such cases, it is also important to consider potential organoleptic changes in the final food.

RECOMMENDATION FOR GOOD MANUFACTURING PRACTICES FOR THE SMOKING PROCESS

39. Foodstuffs such as meat and fish and some types of cheese have been smoked in many countries for centuries. Originally the purpose was to preserve the food, partly by reducing the moisture content and partly through the transfer of anti-microbial and antioxidant components such as phenolic compounds from the smoke to the food.

Fuel used in processing

40. For smoking of food, woods are the fuel normally used, but other types of fuels like bagasse (from sugarcane), corncob and coconut husk might potentially be used (information from Thailand). Fuel used is a critical point for the potential contaminants of the food, e.g., the PAH contamination of food differs if woods or straw is used (Nielsen and Illerup, 2003).

41. PAH are formed in wood smoke by two main routes: either by HACA (hydrogen abstraction/acetylene addition), i.e. by consecutive additions of an acetylenic motif, or by thermodegradation of lignin. During pyrolysis, thermodegradation breaks down furan and pyran heterocycles in lignin, producing a large diversity of volatile compounds while more stable aromatic cores only lose some side groups. This explains why the use of conifer woods, with their higher lignin content and the possibility of a higher contamination of PAH should be avoided.

42. There are some indications that the use of hardwoods for smoking leads to lower PAH levels than the use of soft woods. However, there is conflicting literature on this. Hard woods can be used in form of chips, sawdust or logs². Benzo[*a*]pyrene reaches the highest concentration upon application of spruce, hazel-tree, plum-tree and aspen, whereas the lowest concentration was brought about by apple-tree, alder and maple (Jākabsone and Bartkevics, 2006).

43. Maga et al (1986) reported that the use of the softwood species: mesquite wood resulted in increased levels of benzo[*a*]pyrene compared to the use of hard wood and charcoal. Maga, 1988 proposed to use hard woods instead of soft woods to reduce the PAH content. However, limited investigations are conducted and they are not in total agreement (Guillén et al., 2000). The use of conifer woods should be avoided as they result in very acid products and raise safety concerns in particular increased fire risks because of bistre build-up in chimney (a highly flammable material derived from soot).

44. The conclusion is that the wood species have an influence, in general. However, it has not been possible to find references to recommend the use of more specific wood species and a recommendation is, that the individual species of woods used in smoking processes have to be studied in relation to PAH formation before use.

45. Woods treated with chemicals for preserving, waterproofing, fireproofing etc. should not be used. Such treatments may result in tainting of the food as well as the introduction of other contaminants e.g. dioxin from woods treated with pentachlorophenol (PCP) (Hansen and Hansen, 2003). The woods used for the production of primary products (liquid smokes) shall not have been treated, intentionally or not, with chemical substances during the last six months immediately before felling or after felling, unless it can be demonstrated that the compound used for this treatment does not produce potentially toxic substances during burning.

46. For some foods, the effect of fuel choice on taste may be the critical factor in choosing a fuel. In any event, fuels like e.g., diesel, rubber e.g. tires or waste oil should generally not be used even as a partial component, as they may well lead to increased PAH levels. The use of other fuels than wood for the purpose of smoking foodstuffs should be discouraged.

47. *Fuel and the critical control points.*

- a. The type and composition of wood used to smoke foods, including age of and water content in the wood used. Use hard wood rather than softwood to generate smoke
- b. When other types of fuels like bagasse (from sugarcane), corn cob and coconut husk are used, the use should be subject for a risk assessment
- c. Do not use woods treated with chemicals

² Logs are used to produce smoke by friction.

- d. The use of other types of fuel: Avoiding the use of fuels as diesel fuel, waste products, especially rubber tyres, olive residues and waste oil and other types of fuels that may already contain significant levels of PAH
- e. Particle sizes (saw dust, wood shavings etc)
- f. Influence on the taste of the final food.

Application of the smoke

48. The main groups of chemicals in the smoke are phenolic and carbonylic compounds, acids, PAH and nitrogen oxides and their reaction products. Some examples of components found to be contributing to the smoke flavour are: phenolic compounds, carbonylated phenolic compounds, derivatives, including cyclopentenone, cresols/alkylated phenolic compounds (of guaiacol type) (Selttes, E.J., Elder, T. J. 1981), phenolaldehydes, pentenone, and alcyphenols of the guajacol type (Selttes, E.J and Elder, T.J., 1981).

49. The smoke and critical control points.

- a. The composition of the smoke depending of e.g. the type of wood, the amount of oxygen present and the length of time for which the wood is burned.
- b. The design of the smoking chamber and of the equipment used for smoke/air mixture
- c. Filtering or cooling the smoke where possible

Foodstuffs processing

50. The position of the food in the smoke chamber and the distance between the food and the heat source is a critical point in the smoking process. As PAH is particle bond, longer distance might give lower content of PAH in the smoked food.

51. The fat content of the food fat drippings into the source for the smoke, e.g. the glowing wood might increase the content of PAH in the smoke and thereby in the smoked food.

52. The microbiological quality of the final food product must be evaluated to ensure that there is no potential growth of pathogens during processing and in the final food.

The organoleptic properties of the final products are an essential part of its characteristics. Changes of the methods might not necessary result in the requested products.

53. *The foodstuffs smoked and critical control points are*

- a. The distance between the food and the heat source
- b. The fat content of the food to be smoked
- c. Deposits of smoke particles on the surface and the suitability of the surface for human consumption. For fish, the recommendation could be to prioritise smoking of fish with the skin on.
- d. The microbiological quality after processing
- e. The organoleptic properties of the final food.

Processing

54. Smoke is produced by pyrolysis of the fuel at temperatures of around 300-450°C (and up to 600 °C) in the glow zone. Pyrolysis is the destruction of wood by a heating process. Activation energy provided by electricity allows wood to vaporize into combustible gas, which mix with the combustive agent (air). To avoid flames, airflow needs to be adjusted and controlled in order to prevent going beyond the temperature of inflammation of wood. In this meaning, it is an incomplete combustion, which leads to PAH production.

55. Differences in the smoking processes can lead to highly variable PAH levels in the final food product (European Commission, 2002). The choice of technology for processing is very important for the final concentration of PAH³. The different variables in the processes used should be assessed in relation to a hazard analysis of the parameters critical for potential formation of PAH in a specific process used.

³ *Smoke flavourings* could be an alternative to the smoking process. There are various types of smoke flavour including smoke extract and mixtures of chemicals. In principle, both types of flavourings, especially smoke extracts, may contain PAH. However, levels are tightly regulated through legislation in the EU. The use of smoke flavourings obtained from primary smoke condensates is generally considered to be of lesser health concern than the traditional smoking process. In the production of smoke flavourings, PAH can be removed, and maximum limits for e.g. benz[a]pyrene can be established and met. However, it should be noted that

56. The traditional smoking processes are often divided into three groups after the temperatures used in the smoke chamber during processes:
- Cold* smoking with temperature 18-25 °C. Used for e.g., some fish species and salami-type sausages
 - Semi-warm* with temperatures around 40°C. Used for e.g. some fish species, bacon and pork loin
 - Warm* smoking is smoking combined with heating resulting in a temperature of 70-90°C. Used for e.g. some fish species, and frankfurter type sausages.
57. Replacing direct smoking with indirect smoking can significantly reduce contamination of smoked foods. In modern industrial kilns, an external smoke generator can be operated automatically under controlled conditions to clean the smoke and regulate its flow as it is brought into contact with the food. For more traditional or smaller scale operations, this may not, however, be an option. The best results are produced by installing baffles after the smoke generator equipped with a device for decantation of tar.
58. The type of generator used should be based on an assessment of possible reduction of the PAH content in the final food and where possible include washing of the smoke after the generator and before the smoke chamber. Good results are achieved by installing baffles after the smoke generator equipped with a device for decantation of tar. A more efficient way is to manage the pyrolysis temperature and decanting of heavy phases tanks to a cooling device with baffles.
59. As PAH are particulate bound, a filter may be used to remove particulate material from the smoke. This should reduce potential contamination with PAH. Ultraviolet radiation could be used to reduce the content of benzo[*a*]pyrene in smoked products (Jākabsone and Bartkevics, 2006).
60. Oxygen needs to be adequate to ensure partial/incomplete combustion of the fuel. Too much oxygen may raise the temperature in the glow zone and lead to increased formation of PAH. A lack of oxygen may lead to the formation of more PAH in the smoke, as well as producing carbon monoxide, which may be hazardous to operators.
61. Temperature is of importance for the partial/incomplete combustion of the fuel. The composition of the smoke depends on the temperature, which should be adjusted to minimize PAH formation. However, more data is needed to document which temperatures would be recommendable.
62. In principle, the smoking time should be as short as possible to minimize the exposure of the food surfaces to PAH-bearing smoke. However, in the case of hot smoking, when the product is being cooked at the same time, it will be essential to allow sufficient time for the product to be cooked thoroughly. In case hot smoke is the only heat source (traditional smoke houses), the smoking chamber should be heated before the food products are placed into the smoking chamber. Dependency of time in the smoking and charcoal grilling processes is illustrated by data obtained by Chen and Lin in 1997. Smoking time is not an important parameter as long as the source for smoke is well managed. Moreover, short smoking times may have an impact on food safety and shelf life.
63. There are two types of cleaning steps to be used either during processing or as post process treatment:
- The cleaning of smoke before it enters the smoking chamber. This can be achieved by washing (scrubbing), using a tar condenser, cooling or filtering. All measures to remove particle-bound PAH from the smoke
 - The cleaning of the smoked product itself. In this case rinsing the product or immersing it into water may remove soot and particles containing PAH on the surface of the food.

smoke flavourings may be an additional source of 3-MCPD (3-monochloropropanediol).

The use of smoke flavourings does not necessarily provide the preservative/anti-microbial effect of actual smoking. The microbial food safety of the food must therefore be taken into account in any change from actual smoking to the use of smoke flavouring. Comprehensive studies are lacking on this topic and there are little data available comparing the effects of liquid smoke and traditional smoking processes. There are some results on the antimicrobial effect of liquid smoke on the presence of *Listeria* in smoked salmon. Published results have been mainly obtained in model medium (Sunen et al., 2001 and 2003, Neunlist et al, 2004). Antimicrobial effects vary across types of liquid smoke and microorganisms.

64. The smoking process and critical control points
- a. Whether the smoking process is a direct or indirect process
 - b. Prior assessment of smoke generators by taking account of the resulting PAH content in the smoke
 - c. Adjusting of the airflow to avoid too high temperature in the glowing zone during smoke generation
 - d. Selecting appropriate smoking chamber and device for treatment of air/smoke mixture
 - e. The accessibility of oxygen during the smoking process
 - f. Smoking time: Reducing the time that food is in contact with smoke, this should take the consequences for microbiological safety into consideration
 - g. Reducing the residence time of vapours in the reactor
 - h. Temperature (temperature in the glow zone (in the smoke generation step) and temperature of the smoke in the smoking chamber
 - i. Filtering of smoke or the use of a tar condenser
 - j. The cleaning method and schedule applied in the processing unit.

The scientific background and data to illustrate the exact influence of the use of different types of fuel, time, temperature etc. is limited and specific testing is needed in the hazard analysis of critical control points of the individual processes.

Post smoking treatment

65. When possible, washing or water-cooling of smoke should be used to reduce the content of PAH in the final food. Water-cooling is already used in the meat industry, and this kind of washing of the product after the process may remove PAH-containing particles from the surface of the product (Fabech, B and Larsen, J.C., 1986).
66. However, washing of the product should not be used for fishery products as it could result in lower organoleptic quality and increased microbiological risk. Fish products are often smoked as the whole fish with the skin, and if the skin is not eaten, part of the PAH contamination are removed together with the skin. The recommendation could be to prioritise smoking of fish with the skin on.
67. Post smoking processes and critical control points.
- a. The cleaning of the smoked product itself. In this case soot and particles containing PAH on the surface of the food may be removed by rinsing the product or immersing it into water
 - b. Washing/water cooling might lower organoleptic quality and increased the microbiological safety risk.

COP FOR PRODUCTION OF SMOKED FOOD, summary on the critical control points

PAH content of smoked foods can be minimised by conducting a hazard analysis of the critical control points mentioned below

68. Fuel used in the process
- a. The type and composition of wood used to smoke foods, including age of and water content in the wood used. Use hard wood rather than softwood to generate smoke
 - b. Do not use woods treated with chemicals
 - c. The use of other fuels: Avoiding the use of fuels as diesel fuel, waste products, especially rubber tyres, olive residues and waste oil which may already contain significant levels of PAH
 - d. Particle sizes (saw dust, wood shavings etc)
 - e. Influence on the taste of the final food.

69. The smoke developed and used in the process
 - a. The composition of the smoke depending of e.g. the type of wood, the amount of oxygen present and the length of time for which the wood is burned.
 - b. The design of the smoking chamber and of the equipment used for smoke/air mixture
 - c. Filtering or cooling the smoke where possible
70. The foodstuffs smoked and critical control points
 - a. The distance between the food and the heat source
 - b. The fat content of the food to be smoked
 - c. Deposits of smoke particles on the surface and the suitability of the surface for human consumption. For fish, the recommendation could be to prioritise smoking of fish with the skin on
 - d. The microbiological quality after processing
 - e. The organoleptic properties of the final food.
71. The smoking process and critical control points
 - a. Whether the smoking process is a direct or indirect process
 - b. Prior assessment of smoke generators by taking account of the resulting PAH content in the smoke
 - c. Adjusting of the airflow to avoid too high temperature in the glowing zone during smoke generation
 - d. Selecting appropriate smoking chamber and device for treatment of air/smoke mixture
 - e. The accessibility of oxygen during the smoking process
 - f. Smoking time: Reducing the time that food is in contact with smoke, this should take the consequences for microbiological safety into consideration
 - g. Reducing the residence time of vapours in the reactor
 - h. Temperature (temperature in the glow zone (in the smoke generation step) and temperature of the smoke in the smoking chamber
 - i. Filtering of smoke or the use of a tar condenser
 - j. The cleaning method and schedule applied in the processing unit.
72. Post smoking processes and critical control points.
 - a. The cleaning of the smoked product itself. In this case soot and particles containing PAH on the surface of the food may be removed by rinsing the product or immersing it into water
 - b. Washing/water cooling might lower organoleptic quality and increased the microbiological safety risk.

RECOMMENDATION FOR GOOD MANUFACTURING PRACTICES FOR DIRECT DRYING

73. One of the oldest methods of food preservation is by drying, which reduces water activity sufficiently to delay or prevent bacterial growth. Drying food using the sun and wind to prevent spoilage has been known since ancient times. Water is usually removed by evaporation (air drying, sun drying, smoking or wind drying) but, in the case of freeze-drying food is first frozen, and then water is removed by sublimation.
74. Drying works by removing the water from food. As the bacteria and micro-organisms within the food and from the air need water to grow, drying is preserving the food. The drying process also creates a hard outer-layer, helping to stop micro-organisms from entering the food.
75. With regard to direct and indirect drying processes, direct drying requires less equipment than indirect but could result in higher levels of PAH in the final, dried food.
76. Direct drying can be done either using drying in the sun or using hot combustion gases from burning gases, oil, wood, solid/liquid waste etc.

This COP is divided in direct drying using a) sun, b) other fuels.

Sun drying.

77. When drying by use of the heat from the sun, the potential source of PAH is the environment as a contamination from soil/dust or/and from combustion from industry and traffic.

78. Sun drying of crops should not take place near industrial point sources of combustion of gas, such as roads with heavy traffic, incinerators, coal-fired power stations, cement works etc., or in the immediate proximity of roads with intense traffic. Contamination from drying in such place is expected to be a special problem for foodstuff with a big surface area like, spices. However, covered dryers may protect crops from industrial sources to some extent.

Sun drying process and critical control points

- a. No drying near industrial point sources of combustion of gas, such as incinerators, coal-fired power stations, cement works etc., or in the immediate proximity of roads with intense traffic.
- b. Avoid drying of the products (cacao beans for example) directly on the asphalt or bitumen, which is a source of PAH.

Direct drying processes, other than sun drying.**Fuel used.**

79. Drying in the sun is used in many countries, and besides this different types of fuel are used, e.g. natural gas, peat and mineral oils. Furthermore fuel like woods, rubber, and solid waste might be used in drying processes.

80. For some foods, the effect of fuel choice on taste may be the critical factor in choosing a fuel. In any event, fuels like e.g., diesel, rubber e.g. tires or waste oil should generally not be used even as a partial component, as they may well lead to increased PAH levels.

81. The hot drying gasses can be produced by using various types of fuel resulting in different types of contaminants in the air.

The heat energy of a system must:

- Heat the drying feed to the vaporization temperature of the "light" components
- Vaporize and/or free the liquid/by-products above the solids surface
- Heat solids to the final desired temperature, for the desired duration of time, and
- Heat the vapour to the final desired temperature.

82. The type of fuel used for direct drying of foods has an influence on the formation of PAH (Nielsen and Illerup, 2003).

83. The type and composition of fuel used in the drying process has an influence on the formation of PAH, but insufficient data are available to recommend specific fuels. It is recommended to conduct a risk assessment (HACCP analysis) of the fuel intended to be used, the actual process and foodstuffs to be dried. This assessment should take into account the benefit of using filtering of the gasses.

84. The fuel used in drying processes may also affect the flavour of the final product, and this point is also relevant to consider.

Fuel used in the process and some critical points

- a. Conducting a risk assessment (HACCP analysis) of the fuel used in contact with the foods to be dried
- b. The type and composition of fuel used to dry foods
- c. If woods are use, use hard wood rather than softwood and do not use woods treated with chemicals
- d. The use of other fuels: Avoiding the use of fuels as diesel fuel, waste products, especially rubber tyres, olive residues and waste oil which may already contain significant levels of PAH
- e. Influence on the taste of the final food.

Combustion gasses

85. Drying with combustion gases increased the contamination by 3- to 10-fold; use of coke as fuel resulted in much less contamination than use of oil (Bolling, 1964). Direct contact of oil seeds or cereals with combustion products during drying processes has been found to result in the formation of PAHs and should therefore be avoided, and JECFA recommend that contact of food with combustion gasses be minimized (WHO, 2006).

The combustion gasses developed and used in the process and some critical points.

- a. Contact of food with combustion gasses be minimize

The foodstuffs dried

86. Drying is used for many types of food like meat, many fruits like apples, pears, bananas, mangos, papaya, apricot, and coconut. Drying is also the normal means of preservation for cereal grains such as wheat, maize, oats, barley, rice, millet and rye.

87. Contamination of vegetable oils (including olive residue oils) with PAH usually occurs during technological processes like direct fire drying, where combustion products may come into contact with the oil seeds or oil (Speer et al., 1990; Standing Committee on Foodstuffs, 2001). Direct contact of oil seeds or cereals with combustion products during drying processes has been found to result in formation of PAH and should therefore be avoided. For more data, see also Appendix III

The foodstuffs dried and critical control points are

- a. Direct contact of oil seeds or cereals with combustion products should be avoided.

The direct drying process

88. Common direct drying/heating operations and applications include drying to remove water (and/or other solvents/chemicals) added, left or produced during processing. During direct drying, hot air is blown directly into the foodstuffs and combustion products can therefore directly enter the food. One example of PAH contamination from direct drying in contamination of vegetable oils (including olive residue oils) in which oil has been contaminated with PAH during technological processes (Antonopoulos, K et al., 2006; Menichini, S. et al., 1991).

89. Continuous flow drying, where cereals pass the drying area continuously, is a widespread grain drying method. This technique can be used for drying cereals for food. Direct heating is mainly used with temperatures up to 120 °C for feeds. For foods, indirect heating (external heat generation) and temperatures between 65 and 80 °C are mainly used (bread, malt etc.). The time span for both types of drying is between ½ and 1 hour, depending on the initial moisture content of the grain. (reference to be inserted).

90. Temperature should be optimal for drying without the opportunity for PAH formation. A good homogeneity of the temperature of the air is important to avoid overheating.

91. The drying time should be as short as possible to decrease the exposure of the food to the potentially contaminating gasses as much as possible.

92. The use of active carbon is required for oil seeds and pomace olive oil as the only way to reduce the PAH content when direct drying processing is used. A monitoring system for the PAH content should be established and additional refining steps (with active carbon) must be used when the PAH level in the food is unacceptable.

93. As drying processes could be a potential source of PAH in cereals and oil seeds, there is also a need to control the levels of PAH in agriculture crops post-harvest, with particular reference to the source of contamination, as these crops can have a major impact on PAH intake from food. JECFA recommend avoiding fire drying of seeds, and seek alternative drying techniques (WHO, 2006).

94. Numerous factors, including equipment cost and availability of energy sources often result in similar foods being dried in very different ways.

95. Replacing direct drying with indirect drying can significantly reduce contamination of dried foods. JECFA has recommended that direct during be replaced with indirect drying (WHO, 2006).

The drying process and critical control points

- a. Temperature should be optimal for drying without the opportunity for PAH formation. A good homogeneity of the temperature of the air is important to avoid overheating
- b. Reduce the time that food is in contact with combustion gasses
- c. Keep equipment clean and well maintained (especially driers).

COP FOR PRODUCTION BY USING DIRECT DRYING, except sun drying

Summary on the critical control points.

Fuel used in the process and some critical points

- a. Conducting a risk assessment (HACCP analysis) of the fuel used in contact with the foods to be dried
- b. The type and composition of fuel used to dry foods
- c. If woods are use, use hard wood rather than softwood and do not use woods treated with chemicals
- d. The use of other fuels: Avoiding the use of fuels as diesel fuel, waste products, especially rubber tyres, olive residues and waste oil which may already contain significant levels of PAH
- e. Influence on the taste of the final food.

The combustion gases developed and used in the process and some critical points.

- a. Contact of food with combustion gasses be minimize

The foodstuffs dried and critical control points are

- a. Direct contact of oil seeds or cereals with combustion products should be avoided.

The drying process and critical control points

- a. Temperature should be optimal for drying without the opportunity for PAH formation. A good homogeneity of the temperature of the air is important to avoid overheating
- b. Reduce the time that food is in contact with combustion gasses
- c. Keep equipment clean and well maintained (especially driers).

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Appendix I

Polycyclic aromatic hydrocarbons included in the JECFA Risk Assessment summary.

Common name	CAS name	CAS Registry No.	Abbreviation
Acenaphthene	Acenaphthylene	83-32-9	AC
Acenaphthylene	Acenaphthylene, 1,2-dihydro-	208-96-8	ACL
Anthanthrene	Dibenzo[<i>def,mno</i>]chrysene	191-26-4	ATR
Anthracene	Anthracene	120-12-7	AN
Benz[<i>a</i>]anthracene	Benz[<i>a</i>]anthracene	56-55-3	BaA
Benzo[<i>a</i>]fluorine	11 H-Benzo[<i>a</i>]fluorine	238-84-6	BaFL
Benzo[<i>b</i>]fluorene	11 H-Benzo[<i>b</i>]fluorene	243-17-4	BbFL
Benzo[<i>b</i>]fluoranthene	Benz[<i>e</i>]acephenanthrylene	205-99-2	BbFA
Benzo[<i>ghi</i>]fluoranthene	Benzo[<i>ghi</i>]fluoranthene	203-12-3	BghiF
Benzo[<i>j</i>]fluoranthene	Benzo[<i>j</i>]fluoranthene	205-82-3	BjFA
Benzo[<i>k</i>]fluoranthene	Benzo[<i>k</i>]fluoranthene	207-08-9	BkFA
Benzo[<i>ghi</i>]perylene	Benzo[<i>ghi</i>]perylene	191-24-2	BghiP
Benzo[<i>c</i>]phenanthrene	Benzo[<i>c</i>]phenanthrene	195-19-7	BcPH
Benzo[<i>a</i>]pyrene	Benzo[<i>a</i>]pyrene	50-32-8	BaP
Benzo[<i>e</i>]pyrene	Benzo[<i>e</i>]pyrene	192-91-2	BeP
Chrysene	Chrysene	218-01-9	CHR
Coronene	Coronene	191-07-1	COR
Cyclopenta[<i>cd</i>]pyrene	Cyclopenta[<i>cd</i>]pyrene	27208-37-3	CPP
Dibenz[<i>a,h</i>]anthracene	Dibenz[<i>a,h</i>]anthracene	53-70-3	DbahA
Dibenzo[<i>a,e</i>]pyrene	Naphtho[1,2,3,4- <i>def</i>]chrysene	192-65-4	DbaeP
Dibenzo[<i>a,h</i>]pyrene	Dibenzo[<i>b,def</i>]chrysene	189-64-0	DbahP
Dibenzo[<i>a,i</i>]pyrene	Benzo[<i>rst</i>]pentaphene	189-55-9	DbaiP
Dibenzo[<i>a,l</i>]pyrene	Dibenzo[<i>def,p</i>]chrysene	191-30-0	DbalP
Fluoranthene	Fluoranthene	206-44-0	FA
Fluorene	9H-Fluorene	86-73-7	FL
Indeno[1,2,3- <i>cd</i>]pyrene	Indeno[1,2,3- <i>cd</i>]-pyrene	193-39-5	IP
5-Methylchrysene	Chrysene, 5-methyl-	3697-24-3	5-MCH
1-Methylphenanthrene	Phenanthrene, 1-methyl-	932-69-9	1-MPH
Naphthalene	Naphthalene	91-20-3	NA
Perylene	Perylene	198-55-0	PE
Phenanthrene	Phenanthrene	85-01-8	PHE
Pyrene	Pyrene	129-00-0	PY
Triphenylene	Triphenylene	217-59-4	TRI

TOXICOLOGICAL CONSIDERATIONS, Summary.

JECFA reviewed PAH in February 2005 (WHO 2006).

- b. The Committee concluded that the critical effect of PAH is carcinogenicity. As a number of PAH are also genotoxic, it is not possible to assume a threshold mechanism and a PTWI could not be established. Most epidemiological data refer to occupational and environmental exposure. The available evidence regarding oral exposure to PAH was indirect and did not include data on quantitative exposure, and thus was not suitable for use in the risk assessment for PAH.
- c. JECFA used benzo[*a*]pyrene as a marker of the carcinogenic PAH and evaluated results of recent carcinogenicity studies in mice and rats on benzo[*a*]pyrene and used a margin of exposure approach for the risk assessment of PAH.
- d. The present JECFA evaluation focused on 13 PAH that the Committee identified as being genotoxic and carcinogenic: benz[*a*] anthracene, benzo[*b*]fluoranthene, benzo[*j*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, chrysene, dibenzo[*a,h*]anthracene, dibenzo[*a,i*]pyrene, dibenzo[*a,h*]pyrene, dibenzo[*a,l*]pyrene, indeno[1,2,3-*cd*]pyrene and 5- methylchrysene.
- e. JECFA compared mean and high-level intakes of PAH with the calculated benchmark dose lower confidence limit for PAH and calculated margins of exposure (MOEs) of 25 000 and 10 000, respectively. The MOEs were based on available intake data, and can be a useful tool to prioritize risks. Based on these MOEs, JECFA concluded that the estimated intakes of PAHs were of low concern for human health.
- f. JECFA noted that measures to reduce intake of PAH could include avoiding contact of foods with flames, and cooking with the heat source above rather than below the food. Efforts should be made to reduce contamination with PAH during drying and smoking processes, e.g., by replacing direct smoking (with smoke developed in the smoking chamber, traditionally in smokehouses) with indirect smoking.
- g. JECFA recommended that future monitoring should include, but not be restricted to, analysis of the 13 PAH identified as being genotoxic and carcinogenic, i.e. benzo[*a*]anthracene, benzo[*b*]-, benzo[*j*]-, and benzo[*k*]fluoranthene, benzo[*a*]pyrene, chrysene, dibenzo[*a,h*]anthracene, dibenzo[*a,e*]-, dibenz[*a,h*]-, dibenzo[*a,i*]- and dibenzo[*a,l*]pyrene, indeno[1,2,3-*cd*]pyrene and 5-methylchrysene. In addition, analysis of benzo[*c*]fluorine in food may help to inform future evaluations.
- h. In the European Union, thirty-three PAH were evaluated by the Scientific Committee on Food (European Commission, 2002). Among these, 15, namely benzo[*a*]anthracene, benzo[*b*]-, benzo[*j*]- and benzo[*k*]fluoranthene, benzo[*ghi*]perylene, benzo[*a*]pyrene, chrysene, cyclopenta[*cd*]pyrene, dibenz[*a,h*]anthracene, dibenzo[*a,e*]-, dibenzo[*a,h*]-, dibenzo[*a,i*]-, dibenzo[*a,l*]pyrene, indeno[1,2,3-*cd*]pyrene and 5-methylchrysene, show clear evidence of mutagenicity/genotoxicity in somatic cells in experimental animals *in vivo*.
- i. For most PAH, the carcinogenic potential constitutes the critical effect for the hazard and risk characterization. In general, the evidence of genotoxicity shows considerable overlapping with carcinogenicity in agreement with the mechanistic link between DNA adduct formation, mutations, and cancer outcome following PAH exposure.
- j. With the exception of benzo[*ghi*]perylene, the 15 genotoxic PAH (evaluated by the European Union Scientific Committee on Food) have also shown clear carcinogenic effects in various types of bioassays in experimental animals. Although only benzo[*a*]pyrene has been adequately tested using dietary administration, these compounds may be regarded as potentially genotoxic and carcinogenic to humans. They represent a priority group in the assessment of the risk of long-term adverse health effects following dietary intake of PAH.
- k. In the JECFA Summary report (Joint FAO/WHO Expert Committee on Food Additives, February 2005), the Committee note that they have not received any data on occurrence in the GEMS/food format. However, based on data from the European Union SCOOP task force and from IPCS reports, it was noted that the major foods containing higher concentrations of PAH are meat and fish products, particularly grilled and barbecued products, oils and fats, cereals and dry foods.

1. Some examples are given of the content of PAH in foods after processing of food such as drying and smoking and cooking of foods at high temperatures (grilling, roasting, frying):
 - In uncooked foods the average background values are usually in the range 0.01– 0.1 µg/kg.
 - In barbecued meat levels of the individual PAH, benzo[*a*] pyrene have been found as high as 157µg/kg.
 - In traditional smoked food, an average of benzo[*a*]pyrene was 1.2 µg/kg with a sum of carcinogenic compounds of 9 µg/kg. For modern kilns the values were 0.1 µg/kg and 4.5 µg/kg respectively.
 - A level of 10.7 µg/kg of benzo[*a*]pyrene as been reported in corn oil.

However, national studies has shown much higher concentrations, like e.g. in Finland⁴ where in a study from 2003 the concentrations of benzo[*a*]pyrene varied from zero to 34 µg /kg and that of the total PAH compounds (19 compounds) from 42 to 9000 µg /kg. The study shows that the total PAH concentrations can be very high for instance in smoked meat products.

⁴ National Food Agency, Finland, 2003.

PAH CONTENT IN SOME SMOKED AND DRIED FOODS.

The Appendix give information on content of PAH is some foodstuffs.

- a. Roasting and drying of coffee beans and tea leaves increase the PAH content (Stall and Eisenbrand, 1988). A Finnish study showed that roasted ground coffee and dried tea leaves contained high levels of PAH namely 100-200 microgram/kg and 480-1400 microgram/kg, respectively. However, PAH could not be detected in tea and coffee beverages (Hietaniemi et al., 1999; limits of detection not available). In other studies it has been shown that the PAH contents in the coffee brew were only a few ng/L (Kayali-Sayadi et al., 1999).
- b. For most non-meat products benzo[*a*]pyrene levels were low (Kazerouni et al., 2000). From the SCOOP project average benzo[*a*]pyrene levels of 0.2 µg/kg were reported for both bread and rolls (n = 103) and cereals (n = 63) (European Commission, 2004). For popcorn benzo[*a*]pyrene average concentrations of 0.5 µg/kg was found. The bread/cereal/grain intake for average consumer has been found to cover approximately 30 % of the total intake of benzo[*a*]pyrene (Larsson, 1986; Kazerouni et al., 2001, European Commission, 2002; Duedahl-Olesen et al., 2006), even though individual items in this food group have low levels of benzo[*a*]pyrene.
- c. For dried fruits 71 % of 158 samples had benzo[*a*]pyrene levels below 2 µg/kg. However 10 % of the total number of samples had concentrations of benzo[*a*]pyrene above 100 µg/kg (European Commission, 2004). No comments or explanation of the increased levels was included.
- d. Van der Wielen and co-workers (2006) reported benzo[*a*]pyrene concentrations up to 85 µg/kg in olive oils (n=170), while other vegetable oils (n=170) for human consumption only showed benzo[*a*]pyrene concentrations up to 9 µg/kg. Benzo[*a*]pyrene concentrations ranging from not detected levels to 64 µg/kg have been reported previously for vegetable oils (Dennis et al., 1991, Moret et al., 2000; European Commission, 2004).
- e. Examples of the effect that differences in smoking process can have on PAH levels, are the content of 12 PAH in smoked fishery products from modern smoking kilns that use external smoke generation and have procedures in place to remove compounds with high boiling points such as PAH and particles potentially containing PAH has been compared with products from traditional smoking kilns where the smoke is generated in direct contact with the product.
- f. The average benzo[*a*]pyrene concentration determined was 1.2 µg/kg for the traditional kilns and 0.1 µg/kg for the modern kilns (Karl and Leinemann, 1996). Levels of benzo[*a*]pyrene being higher for traditional smoked fish compared to external smoked fish were confirmed by results on eel (n=7) and salmon (n=3), with even lower concentrations of benzo[*a*]pyrene for cold smoked salmon (Karl and Leinemann, 1996).
- g. In 2005, Yurchenko and Mölder confirmed the trend, where cold smoked mackerel (n=6) and herring (n=4) did not have detectable levels of benzo[*a*]pyrene (< 0.2 µg/kg) in comparison to varieties (n=4) processed by hot smoking with benzo[*a*]pyrene concentrations of 0.7 µg/kg. Analysis of herring (n=7) and mackerel (n=9) produced by either direct or indirect smoking did however not show statistically significant different average concentrations of benzo[*a*]pyrene (Duedahl-Olesen et al., 2006). Increased levels were however found for both one mackerel (0.7 µg/kg) and one herring (3.9 µg/kg) smoked by a direct smoking processes using common alder wood for smoke formation. Recent results on studies on different processing methods of fish are listed in table 1.
- h. Furthermore, collection of data in the European Union Scientific Cooperation Task (European Commission, 2004) revealed an average benzo[*a*]pyrene concentration for fresh fish of 0.2 µg/kg (n=454) including 11 samples from monitoring in contaminated areas. For smoked fish average concentrations of benzo[*a*]pyrene for fish smoked with unknown smoking methods (n=127) and for fish smoked by traditional methods (n=213) were reported as 1.4 µg/kg and 5.3 µg/kg, respectively (European Commission, 2004). In comparison addition of liquid smoke flavouring to fish (n=12) resulted in average benzo[*a*]pyrene concentrations of 0.03 µg/kg.

- i. For fish with edible parts exposed to the smoke increased benzo[*a*]pyrene concentrations were found. This is illustrated by mackerel fillets with concentrations of benzo[*a*]pyrene of 0.4 and 0.9 µg/kg compared to <0.08 µg/kg for whole mackerel (Duedahl-Olesen et al., 2006). In 1996, Karl and Leinemann reported that external smoking of mackerel fillets resulted in a benzo[*a*]pyrene concentration of 0.15 µg/kg (n=11), while traditional smoking of mackerel fillets resulted in levels of 0.6 µg/kg (n=7).
- j. Benzo[*a*]pyrene levels of smoked meat products produced today do not seem to impose problems. The concentration of benzo[*a*]pyrene is well below 5 ppb. Duedahl-Olesen and co-workers reported benzo[*a*]pyrene levels for Danish produced products such as bacon, small sausages and salami well below the maximum of 0.6 µg/kg reported by WHO in 1998 for meat, fish and poultry. Jira (2004) found benzo[*a*]pyrene concentrations of 0.12 µg/kg ranging from 0.05 to 0.35 µg/kg for smoked ham and sausage (n=18).
- k. Larsson concluded already in 1983 that the benzo[*a*]pyrene formation in meat is largely affected by the cooking method and the time for which it is cooked. Kazerouni et al (2001) reported concentrations of benzo[*a*]pyrene for other commercially produced products such as bacon, salami, smoked ham and sausages prepared as package directions of less than 0.1 µg/kg.
- l. In the tables below, both drying and smoking terms such as direct or indirect drying or smoking are used. For direct or traditional smoking or drying the smoke formation source is placed in the same chamber as the final food product, while for indirect smoking or drying, a generator forms smoke externally.

Table 1. Fish

Benzo[a]pyrene concentrations in fish smoked under different processing conditions ($\mu\text{g}/\text{kg}$) n.d. not detected

Food item	Indirect	Direct	Other	Reference
Fresh fish			0.2 (\pm 0.7)	European Commission, 2004
Smoked fish	1.4 (\pm 7.2) (method unknown)	5.3 (\pm 21.7) (traditional)	0.03 (\pm 0.02) (liquid smoke flavouring)	European Commission, 2004
Canned smoked fish	2,2 (n=119)	13,4 (n=30)		Joffe and Bartkevics, 2003
Mackerel	<0.08 (n = 5)	0.18 (n = 4)	One sample, direct 0.72	Duedahl-Olesen et al., 2006
Herring	<0.10 (n = 3)	0.15 (n = 4)	One sample, direct 3.9	Duedahl-Olesen et al., 2006
Mackerel fillets		0.44 – 0.93		Duedahl-Olesen et al., 2006
Mackerel fillets	0.15	0.6		Karl and Leinemann, 1996
Eel	0.02 (n.d. – 0,1)	1.1 (0.3 –3.9)		Karl and Leinemann, 1996
Salmon	0.06	1.0	0.04 (cold smoked)	Karl and Leinemann, 1996
Herring/mackerel		0.7 (hot smoked)	n.d. (cold smoked, LOD = 0.24) n.d. (Fresh herring)	Yurchenko and Mölder, 2005
Salmon		0.8 (hot smoked)	0.4 (cold smoked)	Yurchenko and Mölder, 2005
Fish, not specified	n.d (7 samples; sawdust) n.d.; bagasse and corn cob	5.1; hard wood		Information provided from Thailand; 18 January 2008

Table 2. Meat Benzo[a]pyrene concentrations ($\mu\text{g}/\text{kg}$) in meat products smoked or grilled under different conditions

Food item				References
Smoked meat products	1.7 \pm 6.7 (n= 145, method unknown)	3.3 \pm 11.7(n = 1023, Traditional smoking)	0.02 \pm 0.03 (n=198, Liquid flavouring)	European Commission, 2004
Frankfurter	0.3 (charcoal fire) 0.2 (electric oven) 0.1 (frying pan)	54.2 (log fire) 7.7 (log fire embers) 17.6 (cone fire)		Larsson et al., 1983
Hamburger	0.01 (oven-broiled)	0.01 (pan-fried)	Grilled/barbecued 0.09 (medium), 0.6 (well), 1.5 (very well)	Kazerouni et al., 2001
Hamburger, restaurant grilled/barbecued	0.73 (medium)	1.2 (well)	1.4 (very well)	Kazerouni et al., 2001
Steak	0.01 (Oven-broiled)	0.01 (pan-fried)	4.2 (medium) 4.8 (well) (grilled/barbecued)	Kazerouni et al., 2001
Meat, barbecued	1.5			Lodovici et al., 1995
Pork, barbecued	0.1			Lodovici et al., 1995
Cooked Pattie (70-90% lean)	n.d. – 0.1 (hardwood, charcoal)	26 – 42 (mesquite wood)		Maga, 1986
Smoked meat products	0.12 (smoked cured ham n=8, smoked raw sausage, n=10)			Jira., 2004
Lamb sausage	0.32 \pm 0.02 (standard barbecue practice)	2.81 \pm 0.04 (barbecued under severe conditions)		Mottier et al., 2000
Pork products	0.5 – 2.3 (wood smoked)	2.5 (grilled)	0.2 (liquid flavourings)	Gomaa et al., 1993
Chicken with skin and bone	0.08 (oven-broiled)	0.12 (pan-fried)	4.6 (grilled/barbecued)	Kazerouni et al., 2001
Chicken, whole	0.01 (stewed)	0.01 (roasted)		Kazerouni et al., 2001
Chicken boneless	0.12 (Oven-broiled)	0.10 (pan-fried)	0.4 (grilled/barbecued)	Kazerouni et al., 2001
Duck breast steak	6.9 (0.5 hr smoking) 6.9 (1 hr smoking)	9.0 (1.5 hr smoking) 10.6 (2 hr smoking)	13.9 (3 hr smoking)	Chen and Lin, 1997
Duck breast steak	9.2 Charcoal grilled without skin (0.5 hr) 3.7 Charcoal grilled with skin (0.5 hr)	8.4 Charcoal grilled without skin (1 hr) 5.0 Charcoal grilled with skin (1 hr)	8.5 Charcoal grilled without skin (1.5 hr) 5.0 Charcoal grilled with skin (1.5 hr)	Chen and Lin, 1997
Chicken	n.d. – 0.1 (flavouring, wood smoked)	0.7 – 0.8 (barbecued)		Gomaa et al., 1993
Turkey breast, sausage and bacon	0.1 – 0.4 (wood smoked)		n.d. (LOD = Liquid flavouring)	Gomaa et al., 1993

Table 3. Average, ranges and median of benzo[a]pyrene concentration in µg/kg for vegetable oils analyzed with country of origin including values for references (from Fromberg et al., 2007)

Vegetable oil	N	Average	Range	Median	Origin
Olive oil, extra virgin	46	0.15	<0.2-0.4	0.10	IT, ES, GR, FR, NL
Olive oil	6	0.12	<0.2-0.2	0.10	IT, ES
Rapeseed oil	8	0.15	<0.2-0.3	0.10	DK, BE, DE, AT
Sunflower oil	3	0.4	<0.2-0.8	0.3	IT
Sunflower oil	1	11			NL
Grape seed oil	4	1.0	0.2-1.8	1.0	IT, ES, BE
Sesame oil	1	0.2			DE
Reference					
Virgin olive oil	671	0.4	0.015 - 32	0.2	European Comm., 2004
Virgin olive oil	2		<0.02 - 0.7		Hopia et al., 1986
Virgin olive oil	52		<0.015 - 1.2		Moret et al., 1997
Virgin olive oil	6		< 3		Menichini et al., 1991
Virgin olive oil	3	0.1			Lodovici et al., 1995
Olive oil	280	1.7	0.03 - 89	0.3	European Comm., 2004
Olive oil	32		0.5 - 164		Pupin and Toledo, 1996
Olive pomace oil	268	18	<0.1 - 206	9.6	European Comm., 2004
Olive oil	7	0.7	0.2 - 1.2		Speer et al., 1990
Rapeseed oil, deod.	2	0.8	0.3 - 1.3		Larsson et al., 1987
Rapeseed oil	18	0.3	<0.03 - 1.3	0.1	European Comm., 2004
Refined rapeseed oil	24	1.8	0.3 - 69		Dennis et al., 1991
Sunflower oil	5	0.7	<0.1 - 0.8		Speer et al., 1990
Sunflower oil	201	3.1	<0.015 - 232	0.4	European Comm., 2004
Grape seed oil	92	4.2	0.05 - 73	0.6	European Comm., 2004
Grape seed oil	20	20	8.6-44		Moret et al., 2000

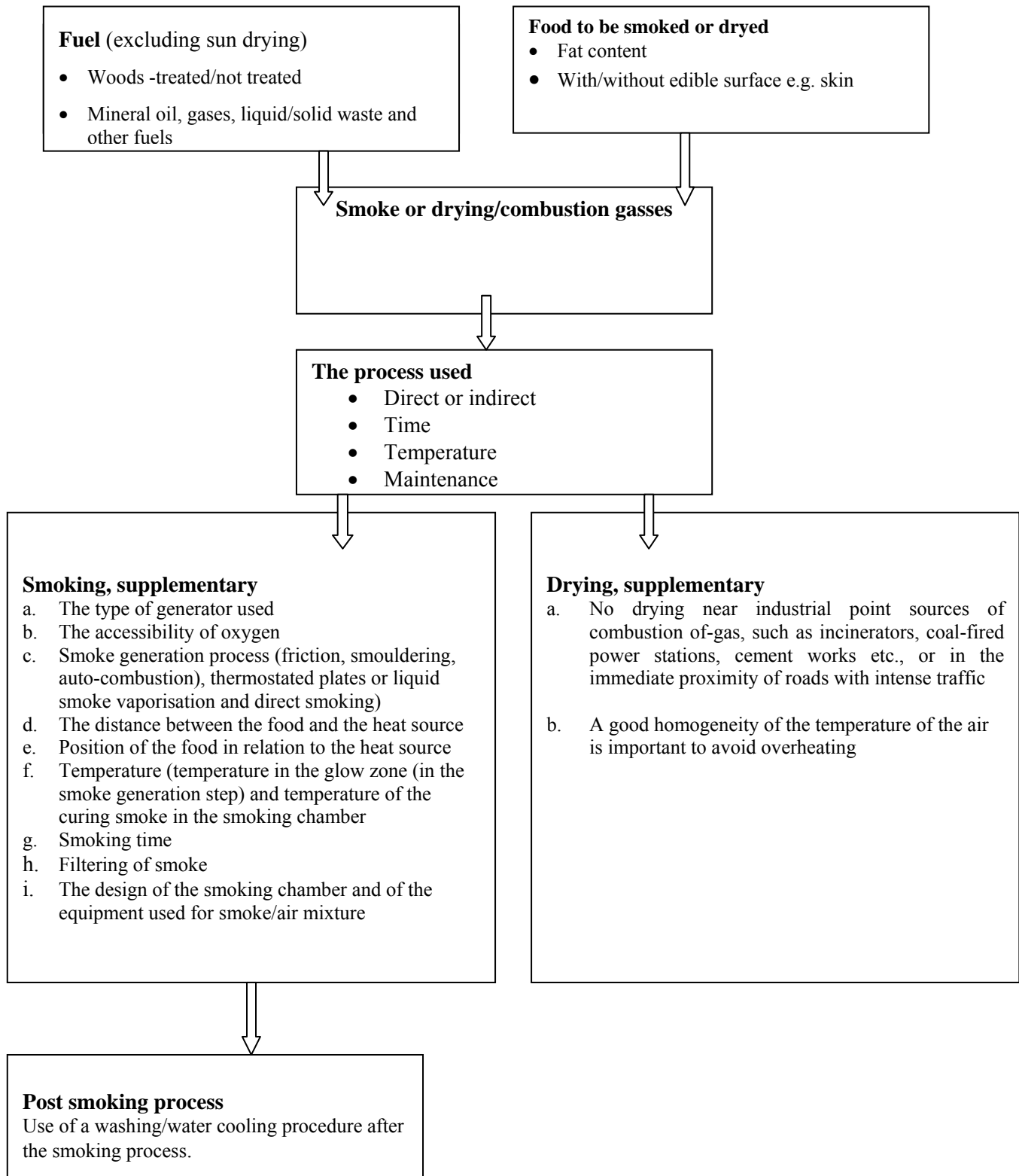
Deod. = deodorized oil.

Origin codes: AT = Austria, BE = Belgium, DE = Germany, DK = Denmark, ES = Spain, FR = France, GR = Greece, IT = Italy, NL = Holland.

Table 4. Other foodstuffs. Benzo[a]pyrene concentrations (µg/kg) in other types of food.

Food item	N	BaP average	Median	Reference
Bread and rolls	103	0.16 (± 0.55)	0.05	European Commission, 2004
Cereals	63	0.16 (± 0.31)	0.05	European Commission, 2004
Dried fruits	158	48.1 (± 5.30)	0.25	European Commission, 2004

Flow chart indicating critical control points



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