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Carcinogenicity of consumption of red and processed meat: What about environmental contaminants?

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ABSTRACT

In October 26, 2015, the International Agency for Research on Cancer (IARC) issued a press release informing of the recent evaluation of the carcinogenicity of red and processed meat consumption. The consumption of red meat and processed meat was classified as “probably carcinogenic to humans”, and as “carcinogenic to humans”, respectively. The substances responsible of this potential carcinogenicity would be generated during meat processing, such as curing and smoking, or when meat is heated at high temperatures (N-nitroso-compounds, polycyclic aromatic hydrocarbons and heterocyclic aromatic amines). However, in its assessments, the IARC did not made any reference to the role that may pose some carcinogenic environmental pollutants, which are already present in raw or unprocessed meat. The potential role of a number of environmental chemical contaminants (toxic trace elements, polycyclic aromatic hydrocarbons, polychlorinated dibenzo-*p*-dioxins and dibenzofurans, polychlorinated biphenyls, polybrominated diphenyl ethers, polychlorinated diphenyl ethers, polychlorinated naphthalenes and perfluoroalkyl substances) on the carcinogenicity of consumption of meat and meat products is discussed in this paper. A case-study, Catalonia (Spain), is specifically analyzed, while the influence of cooking on the concentrations of environmental pollutants is also reviewed. It is concluded that although certain cooking processes could modify the levels of chemical contaminants in food, the influence of cooking on the pollutant concentrations depends not only on the particular cooking process, but even more on their original contents in each specific food item. As most of these environmental pollutants are organic, cooking procedures that release or remove fat from the meat should tend to reduce the total concentrations of these contaminants in the cooked meat.

Keywords: Meat and meat products; environmental contaminants; dietary exposure; cooking; carcinogenicity

1. Introduction

In October 26, 2015, the International Agency for Research on Cancer (IARC) issued a press release (No. 240) on the results of the recent evaluation by this agency, which is the specialized cancer agency of the World Health Organization (WHO), of the carcinogenicity of red and processed meat consumption (IARC, 2015). Based on data of the scientific literature, 22 experts from 10 countries classified the consumption of red meat as “probably carcinogenic to humans” (Group 2A), whereas processed meat was classified as “carcinogenic to humans” (Group 1). Additional information on these assessments has been published in the Lancet Oncology (Bouvard et al., 2015), as an advance of a monograph of the IARC on this subject, whose publication has been already announced (volume 114). Bouvard et al. (2015) reported that the largest body of epidemiological data concerned colorectal cancer. Although the mechanisms responsible of the carcinogenicity of red and processed meat are not clearly established yet, Bouvard et al. (2015) highlighted the presence of N-nitroso-compounds (NOCs), polycyclic aromatic hydrocarbons (PAHs) and heterocyclic aromatic amines (HAAs), well known (or suspected) carcinogenic chemicals, in meat processing such as curing and smoking (NOCs, PAHs), or when meat is heated at high temperatures (HAAs). It is certainly well established that processing and cooking of meats may produce these known or suspected carcinogens (Alaejos et al., 2008; De Mey et al., 2015; Herrmann et al., 2015; Kim et al., 2013; Larsson, 1986; Trafialek and Kolanowski, 2014). However, due to the practically unavoidable presence of other carcinogenic compounds, which are already present in raw or unprocessed meats, we believe that these chemicals are not the only potentially carcinogenic substances in meat and meat products. These other substances are well known environmental pollutants such as some heavy metals, polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), dioxin-like polychlorinated biphenyls (PCBs), etc. We feel this is an issue clearly worthy of being taken into account in order to establish the global causes of the carcinogenicity of consumption of red and processed meat. Therefore, the role of a number of environmental pollutants on the potential carcinogenicity of consumption of meat and meat products is discussed in this paper.

2. Environmental pollutants in meat and meat products

Meat and meat products have an important nutritional value. There is wide scientific evidence that demonstrates the benefits of meat consumption in a healthy diet. Meat and meat products are a major source of nutrients, being a great source of protein of high biological value, as well as a great source of essential amino acids, B vitamins such as vitamin B12, as well as a number of essential trace elements, with particular relevance for iron (Klurfeld, 2015; McAfee et al., 2010; Murphy et al., 2011; Pereira and Vicente, 2013; Zanovec et al., 2010; Zhang et al., 2010). However, it is also known that certain dietary habits can contribute to compromised health by being a source of exposure to toxic contaminants. Specifically, for meat and meat products the health risks for the consumers are mainly related to micropollutants and/or process-induced toxicants. Micropollutants are generated by human activity, or may come from veterinary or plant treatments, being eventually transferred to foodstuffs, including meats. In turn, process-induced toxicants are formed during food processing such as heating or smoking (Engel et al., 2015).

Many of these potential toxicants are fat soluble, and therefore, any fatty food often contains higher levels of micropollutants than does vegetable matter. Consequently, an issue of concern related with a frequent consumption of certain foodstuffs (including of course meat and meat products) is the health risks potentially derived from exposure to chemical pollutants contained in those food items. A number of recent studies have shown that highly consumed foods, and with a considerable nutritional value, can be also a potential source of human exposure to various environmental contaminants, whose potential toxicity is well known. These pollutants include inorganic toxic elements such as arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb), PAHs, pesticides, polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polychlorinated diphenyl ethers (PCDEs), polychlorinated naphthalenes (PCNs), and perfluoroalkyl substances (PFASs). Information on the human exposure to these inorganic and organic environmental pollutants, many of them persistent organic pollutants (POPs), can be found in a recent review on the presence of nutrients and chemical pollutants in fish and shellfish (Domingo, 2015).

3. Balancing health benefits and chemical risks of regular consumption of meat and meat products. A case-study: Catalonia, Spain

To the best of our knowledge, the most wide and complete surveillance program on the trends in the concentrations of a number of environmental pollutants in food and the human dietary intake of those pollutants, has been performed in our laboratory (Reus, Catalonia, Spain). The surveillance program started in 2000. The first survey (BF1) was performed between 2000 and 2002, when the concentrations of the following contaminants were analyzed in a number of foodstuffs, belonging to various food groups: As, Cd, Hg and Pb (Llobet et al., 2003a), PCDD/Fs (Llobet et al., 2003b), PCBs (Llobet et al., 2003c), PBDEs (Bocio et al., 2003), PCNs (Domingo et al., 2003), hexachlorobenzene (Falcó et al., 2004), PCDEs (Bocio et al., 2004) and 16 PAHs (Falcó et al., 2003). In 2006-2008, we carried out a second survey, and in 2008 we initiated the third and last survey of the program. The results of that case-study (Catalonia) corresponding to meat and meat products are next summarized.

3.1. Experimental design

The food items analyzed in our first survey (BF1) were the following: fish and shellfish (hake, sardine, mussel) and tinned fish (tuna, sardine); vegetables (lettuce, tomato, potato, green beans, cauliflower); fresh fruits (apple, orange, pear); pulses (lentils, beans); cow milk (whole, semi-skimmed) and dairy products (yogurt, cheese); cereals (bread, pasta, rice); fats (margarine) and oils (olive, sunflower), and hen eggs. The group of meats was made on beef (steak, hamburger), pork (loin, sausage) and lamb (steak) as red meats, and chicken (breast) as white meat, while ham, hot dogs and salami were selected as meat products. All the foodstuffs were randomly obtained in local markets, large supermarkets and grocery stores from seven cities of Catalonia, with a number of inhabitants between 150,000 and 1,800,000. To establish the daily dietary intake of the analyzed pollutants by the population of Catalonia, we multiplied the concentration of the specific contaminant found in each specific food item by the estimated daily consumption of the respective food group. The total dietary intake of each pollutant was then calculated by summing each product over all the food groups. During 2006–2008, the second survey (BF2) of the surveillance program was performed. The experimental design of that survey was basically the same than the previous one (BF1), but the number of cities in which food samples were purchased was increased to 12, and a new food group, bakery products, was also included. Finally, the number of fish and shellfish species analyzed was increased from 3 to 14. The last survey (BF3) of the surveillance program started in 2008, being the food items acquired in the same 12 cities of the previous survey (BF2), and divided into the same 12 food groups. In the three surveys of the program, the concentrations of the pollutants in all foodstuffs were analyzed in *composite* samples, which were made up by a minimum of 8 and a maximum of 24 individual samples of each food item. Only edible parts of the foodstuffs were included in the composites. Usually, 2-3 composite samples were prepared for the analysis of each environmental contaminant. For calculations, when the concentration of one of the pollutants was under the limit of detection (LOD), we generally assumed that the value was equal to one-half of the LOD (ND = 1/2 LOD). We next summarize the concentrations of the various environmental pollutants in meat and meat products. Data are grouped according to the chemical characteristics of the environmental contaminants.

3.2. *Trace elements*

In the BF1, BF2 and BF3 surveys, among the food groups (11 or 12) in which the foodstuffs were respectively classified, all meat and meat products were taken together as belonging to an only group. For BF1, the concentrations of As, Cd, Hg and Pb were: 0.020, 0.005, 0.0015 and 0.0025 µg/g of fresh weight, respectively, while in the BF2 the average concentrations were <0.100, 0.006, <0.100 and 0.043 µg/g for these same elements. The highest levels of Cd and Pb (the only detected elements) were found in the samples of pork sausage (0.044 and 0.090 µg/g, respectively). Finally, in the BF3 the mean concentrations of As, Cd, Hg and Pb in the composite samples of meat and meat products were respectively: 0.013, 0,007, 0.0011 and 0.0072 µg/g, with the highest level corresponding to Pb in cured ham (0.172 µg/g of wet weight). For a standard male adult (70-kg, body weight), the exposure to these elements through the diet, with estimated consumptions of meat and meat products of 185 g/day (BF1), 172 g/day (BF2) and 172 g/day (BF3), was 4.44, 0.00 and 0.00 µg/day for As; 1.11, 0.00 and 0.80 µg/day for Cd; 2.22, 0.00 and 1.76 µg/day for Hg; and 4.44, 7.16 and 10.21 µg/day for Pb (Llobet et al., 2003a; Marti-Cid et al., 2008a; Martorell et al., 2011). The calculations of the dietary exposure to these race elements in the BF2 and BF3 surveys were carried out assuming ND = 0.

3.3. Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)

In the BF1 survey, the concentrations of PCDD/Fs ranged between 49.82 pg WHO-TEQ/kg of fresh weight for lamb, and 71.20 pg WHO-TEQ/kg of fresh weight for pork and pork products, with an estimated daily intake of 12.09 pg WHO-TEQ from all meat and meat products. This means a percentage of 13% of the total daily dietary intake of PCDD/Fs by a male adult living in Catalonia (Llobet et al., 2003b). In the BF2, the mean concentration of PCDD/Fs in the composite samples of meat and meat products was 17.0 pg WHO-TEQ/kg fresh weight, with the lowest and highest values found in veal steak (0.008) and hamburger (0.037), respectively (Llobet et al., 2008). The estimated dietary intake of meat and meats products for an adult male was 2.62 pg WHO-TEQ/day, meaning 10.2% of the total daily dietary intake of PCDD/Fs. In the BF3, the levels of PCDD/Fs in meat and meat products ranged between 5 and 24 ng WHO-TEQ/kg of fresh weight, for the samples of loin of pork and those of hot dogs, with 6 ng WHO-TEQ/kg for veal steak and chicken breast, and 22 ng WHO-TEQ/kg for salami. The mean concentrations of PCDD/Fs in meat and meat products was 11 ng WHO-TEQ/kg, which means an estimated dietary intake of 1.27 pg WHO-TEQ/day (Perelló et al., 2012), with a 10.0% of the total daily dietary intake of PCDD/Fs.

3.4. *Polychlorinated biphenyls (PCBs)*

The concentrations of 11 PCB congeners (IUPAC No. 28, 52, 77, 101, 105, 118, 126, 138, 153, 169 and 180) were determined in our BF1 survey. The level of all PCBs in the group of meat and meat products was 373.55 ng/kg of fresh weight, which was equivalent to 47.85 pg WHO-TEQ/kg, when calculated on the basis of the five congeners (IUPAC No. 77, 105, 118, 126 and 169) for which, at that time, values of WHO-TEFs were established (Llobet et al., 2003c). The highest concentration of the sum of all PCBs (pg WHO-TEQ/kg) was detected in the composite samples of pork and pork products (68.17), while the lowest level of that sum was found in the chicken samples (17.65). The estimated intake of PCBs for an adult (20-65 years old) male was 8.85 pg WHO-TEQ/day (5.9% of the total daily dietary intake of PCBs). In the BF2 survey, the concentrations of 18 PCB congeners were analyzed. They included the previous 11 congeners, together with PCBs 81, 114, 123, 156, 157, 167 and 189, being the congeners No. 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169 and 189 classified as dioxin-like PCBs (DL-PCBs). The concentration of all PCBs in the group of meat and meat products was 127.3 ng/kg of fresh weight, which was equivalent to 19.0 pg WHO-TEQ/kg (Llobet et al., 2008). The highest concentration of the sum of the 18 PCBs (pg WHO-TEQ/kg) was detected in beef hamburger (67 pg WHO-TEQ/kg), while the lowest levels were found in the veal steak samples (6 pg WHO-TEQ/kg) and those of lamb (7 pg WHO-TEQ/kg) and chicken (7 pg WHO-TEQ/kg). The estimated intake of PCBs for an adult male was 2.24 pg WHO-TEQ/day (4.3% of the total daily dietary intake of DL-PCBs).

The levels of the same 18 PCB congeners were again determined in the BF3 survey. The concentration of all PCBs in the group of meat and meat products was 109.5 ng/kg of fresh weight, which was equivalent to 6.0 pg WHO-TEQ/kg (Perelló et al., 2012). The highest concentration of the sum of the 18 PCBs (pg WHO-TEQ/kg) corresponded to the samples of hot dog and salami (both with 11 pg WHO-TEQ/kg), being the lowest levels found in the samples of veal steak samples, loin of pork, chicken breast, and cured and boiled ham (all with 4 pg WHO-TEQ/kg). The estimated intake of DL-PCBs for an adult male living in Catalonia was 0.84 pg WHO-TEQ/day (3.2% of the total daily dietary intake of DL-PCBs).

3.5. *Polybrominated diphenyl ethers (PBDEs)*

In our initial survey (BF1), the mean concentrations of PBDEs (sum tetra- to octaBDEs) were determined (Bocio et al., 2003). In the 15 composite samples of meat and meat products that were analyzed, the PBDE concentrations (ng/kg fresh weight) ranged between 13.5 and 24.9 for hexaBDEs and pentaBDEs, respectively, being the sum of all 5 groups of homologues of PBDEs, 109.2 ng/kg fresh weight. The lowest and highest PBDE levels corresponded to chicken (10 ng/kg fresh weight) and pork and pork products (172 ng/kg fresh weight), respectively. For the adult population of Catalonia, the estimated dietary intake of PBDEs from the group of meat and meat products was 20.2 ng/day, which means a 20.8% of the total daily dietary intake of PBDEs. In addition to the sum tetra- to octaBDEs, the following six tetra-through heptabrominated congeners were also individually analyzed: PBDEs 47, 99, 100, 153, 154 and 183. The ∑PBDEs (tetra to octa) for the samples of meat and meat products was 49.9 ng/kg of fresh weight, with the lowest and highest concentrations found in hot dogs (87.6 ng/kg of fresh weight) and pork sausage (64.7 ng/kg of fresh weight), and in veal steak (23.4 ng/kg of fresh weight) and chicken breast (29.6 ng/kg of fresh weight), respectively (Domingo et al., 2008). With respect to the individual congeners, the highest values corresponded to the salami samples: 29.0 and 22.0 ng/kg for BDE-99 and BDE-47, respectively. High values of these two congeners were also found in the samples of hot dogs (16.0 and 21.0 ng/kg) and pork sausages (12.5 and 14.0 ng/kg). In the samples of all analyzed meat and meat products, the concentration of the congeners ranged between 1.6 (BDE-100 and BDE-154) and 9.0 ng/kg (BDE-99). The estimated dietary intake of PBDEs from the consumption of meat and meat products by a standard adult man living in Catalonia was 6.8 ng/day. PBDEs were not analyzed in the BF3 survey (Domingo, 2012a).

3.6. *Hexachlorobenzene (HCB)*

In the BF1 survey, the concentrations of HCB in composite samples of meat and meat products purchased in Catalonia, ranged between 0.353 (pork sausages) and 0.319 ng/g fresh weight (hot dogs) in the upper part of the range, and 0.007 (breast chicken) and 0.023 ng/g fresh weight (boiled ham) in the lower part of the range. The mean concentration was 0.173 ng/g fresh weight (Falcó et al., 2004). The estimated dietary intake of HCB derived from the consumption of meat and meat products was 31.98 ng/day for an adult male (19% of the total daily dietary intake of HCB), being only surpassed by the group of dairy products (55%), and close to the group of fish and other seafood (14%). In the BF2 survey, the HCB levels ranged between 0.305 (salami) and 0.210 ng/g fresh weight (hot dogs) in the upper part of the range, and 0.012 (loin of pork) and 0.027-0.029 ng/g fresh weight (boiled ham and breast chicken) in the lower part of the range. The mean concentration was 0.112 ng/g fresh weight (Martí-Cid et al., 2008b). The estimated dietary intake of HCB derived from the consumption of meat and meat products was 12.83 ng/day for an adult male (18% of the total). In our last survey (BF3), the HCB levels ranged between 0.265 (hot dogs) and 0.140 ng/g fresh weight in the upper part of the range, and 0.015 (boiled ham) and 0.005 ng/g fresh weight (breast chicken) in the lower part of the range. The mean concentration was 0.0083 ng/g fresh weight (Perelló et al., 2012). The estimated dietary intake of HCB derived from the consumption of meat and meat products was 9.97 ng/day for an adult male (26% of the total), being this food group that showing the greatest contribution (followed by the dairy products) to the total daily dietary intake of HCB.

3.7. *Polychlorinated naphthalenes (PCNs)*

In the BF1 survey, the concentrations of tetra-, penta-, hexa-, and hepta-CNs, those of octachloronaphthalene, and the mean sum of PCNs were determined in composite samples of meat and meat products (Domingo et al, 2003). The mean concentration of the ∑PCNs (tetra-octa) was 18 pg/g fresh weight, with a range between 0.3 (octaCN) and 10 pg/g fresh weight (∑tetraCNs). For an adult male, the dietary exposure to PCNs through the consumption of meat and meat products was 3.25 ng/day, meaning 7% of the total, a percentage similar to that of fish and shellfish and dairy products, and notably lower than that of cereals. In the BF2 survey (Martí-Cid et al., 2008c), the mean concentration of the ∑PCNs (tetra-octa) was 2.8 pg/g fresh weight with a range between 0.2 (∑hexaCNs, ∑heptaCNs and octaCN) and 1.7 ∑tetraCNs. The highest levels of the ∑PCNs were detected in salami (5.8 pg/g fresh weight) and hot dog (3.8 pg/g fresh weight), while the lowest concentrations were found in chicken (1.7 pg/g fresh weight). For an adult male, the dietary exposure to PCNs through the consumption of meat and meat products was 0.42 ng/day, meaning 5.8% of the total, a percentage notably lower than those of the food groups showing the highest contribution to the total intake of PCNs: fish and seafood (26.9%) and cereals (26.5%). No data regarding the BF3 survey are currently available.

3.8. *Polychlorinated diphenyl ethers (PCDEs)*

In our first survey (BF1), the concentrations of tetra-, penta, hexa-, hepta- and octaCDEs, and the mean sum concentration of PCDEs were determined in composite samples of meat and meat products (Bocio et al, 2003). The concentrations of PCDEs were, for all homologues (tetra- to octaCDE), under the respective detection limits. In fact, PCDEs were only detected in samples of fish and shellfish (fresh and tinned). Therefore, the daily dietary intake of PCDEs could be estimated only very roughly. For it, we assigned to the non-detected (ND) concentrations of PCDEs in the samples of meat and meat products, values of ND = 1/2 LOD. The dietary exposure to PCNs through the consumption of meat and meat products was estimated 0.3 ng/day vs. a total intake of 45 ng/day, for which fish and other seafood contributed with 38 ng/day. In the BF2 survey (Martí-Cid et al., 2008c), the mean concentration of PCDEs could be only detected in the fish and other seafood samples. Using the same criteria than that used in the BF1, for an adult male, the dietary exposure to PCDEs through the consumption of meat and meat products was 0.18 ng/day vs. a total intake of 51.68 ng/day, from which 50.24 ng/day came from the consumption of fish and shellfish. As for other environmental pollutants measured in the BF1 and BF2 surveys, no data regarding the levels of meat and meat products in BF3 survey are available.

3.9. *Polycyclic aromatic hydrocarbons (PAHs)*

In our BF1 survey, we determined in 11 food groups the concentrations of 16 PAHs (naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, benzo[g,h,i]perylene, and indeno[1,2,3-c,d]pyrene) (Falcó et al., 2003). In meat and meat products, the concentrations of the analyzed PAHs ranged between 0.038 and 0.042 µg/kg fresh weight for dibenzo[a,h]anthracene and indeno[1,2,3-c,d]pyrene, respectively, and 4.638 and 2.437 µg/kg fresh weight for phenanthrene and naphthalene, respectively. The total PAH concentration in that food group was 13.4 µg/kg fresh weight, being only overwhelmed by the group of cereals (14.5 µg/kg fresh weight). Regarding the intake of PAHs through the consumption of meat and meat products by an adult male, amounts of 0.018, 0.331 and 2.48 µg/day were estimated for benzo[a]pyrene, the sum of the 7 probable human carcinogens according to the US EPA, and the sum of the 16 analyzed PAHs. Among the 11 food groups, meat and meat products ranked the third one for the contribution of benzo[a]pyrene, and the second for both the sum of the 7 probable human carcinogens and the sum of the 16 PAHs. In all cases the first contribution corresponded to the group of cereals.

The concentrations of the same 16 PAHs were again determined in our BF2 survey (Martí-Cid et al., 2008d). In that survey, and according to the food groups, the highest levels of total PAHs were detected in meat and meat products, 25.56 µg/kg fresh weight, being cereals (20.44 µg/kg) in second place. The highest contribution to total PAHs was found in the samples of salami (189.28 µg/kg), followed at a great distance by hot dogs (13.57 µg/kg). In contrast, the samples of loin of pork (1.12 µg/kg) and those of boiled ham (1.44 µg/kg) were the lowest contributors. The concentrations of the individual PAHs ranged between 0.09 µg/kg fresh weight for indeno[1,2,3-c,d]pyrene and benzo[g,h,i]perylene (both), and 9.42 µg/kg fresh weight for phenanthrene. With respect to the exposure to PAHs through the consumption of meat and meat products by an adult male, values of 0.026, 0.285 and 3.282 µg/day were estimated for benzo[a]pyrene, the sum of the 7 probable human carcinogens according to the US EPA, and the sum of the

16 PAHs. Among the 12 food groups included in that survey, meat and meat products ranked the first one for the contribution of benzo[a]pyrene and the sum of the 7 probable human carcinogens, and the second one for the sum of the 16 PAHs, with cereals being the first one.

In our BF3 survey, the highest levels of total PAHs were again detected in meat and meat products, 38.99 µg/kg fresh weight, followed by the group of oils and fats (18.75 µg/kg) (Martorell et al., 2010). The highest contribution to total PAHs was also found in the samples of salami (364.91 µg/kg), followed again at a great distance by the samples of hot dogs (13.86 µg/kg). In contrast, the samples of loin of pork (1.12 µg/kg) and those of boiled ham (1.44 µg/kg) were the lowest contributors. The concentrations of the individual PAHs for the mean samples of meat and meat products ranged between 0.03 µg/kg fresh weight, for dibenzo[a,h]anthracene, and 9.42 µg/kg fresh weight, for phenanthrene. The exposure to PAHs through the consumption of meat and meat products by an adult male was 0.019, 0.209 and 4.75 µg/day, estimated for benzo[a]pyrene, the sum of the 7 probable human carcinogens (according to the US EPA), and the sum of the 16 PAHs, respectively. The group of meat and meat products was again in the first place for the contribution of benzo[a]pyrene, the sum of the 7 probable human carcinogens, as well as the sum of the 16 PAHs (with cereals in the second place).

3.10. Perfluoroalkyl substances (PFASs)

Recently, the available scientific information on the levels of PFASs in food, and about the health risks of the dietary exposure to these compounds, was extensively reviewed (Domingo, 2012b). In our laboratory (Ericson et al., 2008), we determined the levels of 11 PFASs in composite samples constituted of the most frequently consumed foodstuffs by the population of Tarragona County (Catalonia, Spain). We also estimated the dietary intake of those PFASs by that population. In the group of meat and meats products, the following samples were included: veal (steak, hamburger), pork (sausage, hot dogs, steak, hamburger, ham), chicken (breast, thighs, sausages) and lamb (steak). Perfluorooctane sulfonate (PFOS) was the only PFAS that could be detected in these samples, with mean values of 0.045, 0.021, 0.028, and 0.040 ng/g fresh weight for pork, chicken, veal and lamb, respectively. For an adult male living in Catalonia, the dietary intake of PFOS was 1.07 ng/kg/day, being fish and shellfish the group with the highest contribution to the total dietary intake, followed by the groups of dairy products, and the group of meat and meat products.

4. Other recent data on human exposure to chemical contaminants through consumption of meat and meat products

In 1996-1998, as a part of a surveillance program on the health risks for the population living in the neighborhood of the only hazardous waste incinerator (HWI) in Spain, our laboratory analyzed (baseline or background study) the concentrations of PCDD/Fs in a number of the most consumed foods by the population living in the zone (Tarragona County, Catalonia) under potential direct influence of the emissions of pollutants from the stack. The daily intake of PCDD/Fs through the diet by that population was also estimated (Domingo et al., 1999). Composite samples of the following meats were analyzed: beef (hamburger, steak, liver), pork (sausage, hot dogs, steak, liver, hamburger), chicken (liver, breast, sausage) and lamb (steak). The intake of PCDD/Fs through meat consumption was estimated to be 20.76 pg I-TEQ, which was equivalent to 9.88% of the total daily dietary intake of PCDD/Fs. The highest PCDD/F concentrations in meats were found in beef and lamb samples. The dietary intake of PCDD/Fs by that population was again assessed in 2002 (Bocio and Domingo, 2005), 2006 (Martí-Cid et al., 2008e) and 2012 (Domingo et al., 2012). In those studies, the kind of analyzed meats was basically the same, although composite samples of some meat products (salami and boiled ham) were also included (Domingo et al., 2012). The intakes of PCDD/Fs through the consumption of meat and meat products were 5.4, 2.26 and 3.18 pg WHO-TEQ/day, for the 2002, 2006 and 2012 studies, respectively, which mean contributions to the total dietary intake of PCDD/Fs of 7.8%, 8.0% and 9.6% (Bocio and Domingo, 2005; Domingo et al., 2012; Martí-Cid et al., 2008e). In general terms, in these 3 studies, the highest values of PCCD/Fs in meats were detected in lamb (0.040 ng WHO-TEQ/kg fresh weight, 2002 study) and beef (0.030 ng WHO-TEQ/kg fresh weight, in the 2002 and 2012 studies), being the lowest levels found in chicken (0.011 and 0.008 ng WHO-TEQ/kg fresh weight, in the 2008 and 2012 studies, respectively).

The levels in foods of the toxic metals As, Cd, Hg, Pb, as well as the trace elements beryllium (Be), chromium (Cr), manganese (Mn), nickel (Ni), tin (Sn), thallium (Tl), and vanadium (V), were also determined during the same surveillance program, being the exposure to these elements by the population living near the HWI also estimated. Some of these elements are also potentially carcinogenic in humans. A baseline (background) study was performed in 1996-1998 (Llobet et al., 1998), followed by surveys carried out in 2003 (Bocio et al., 2005), 2006 (Martí-Cid et al., 2009) and 2013 (Perelló et al., 2015). Analyzed meats included composite samples of veal, lamb, pork and chicken. The results varied notably depending on the year of sampling, the specific samples, as well as the respective metal. All that information is summarized in Perelló et al. (2015).

The levels of contamination with POPs and its relationship with dietary habits have been also studied in the population from the Canary Islands, another Spanish region. Boada et al. (2014) assessed the role of the dietary intake of animal products as a probability factor for increased serum POPs. Regarding to meat, it was found that while poultry and rabbit consumption increased the probability of having high levels of non-DDT-derivative pesticides, sausage, lard and bacon consumption decreased the probability of having high levels of these pesticides. In turn, poultry and rabbit consumption increased also the probability of having detectable levels of markers PCBs, while sausage consumption increased the probability of having detectable levels of dioxin-like PCBs (DL-PCBs). In another recent study of the same research group, the concentrations of PAHs, organochlorine pesticides, and dioxin-like PCBs were determined in 100 samples of meat and charcuterie (Rodriguez-Hernandez et al., 2015a). The results indicated that the consumption of beef, pork, lamb, chicken, and "chorizo", represents a relevant carcinogenic risk for consumers (carcinogenic risk quotient between 1.33 and 13.98). In order to reduce carcinogenic risk, it was suggested not to surpassing the number of 5 servings of beef/pork/chicken (considered together) (Rodriguez-Hernandez et al., 2015a). These authors also showed that the consumption of organic meat does not diminish the carcinogenic potential associated with the intake of POPs. Seventy-six samples of meat (beef, chicken, and lamb) of two modes of production (organic and conventional) were acquired and the levels of 33 carcinogenic POPs were quantified. The results showed that there was not any sample completely free of carcinogenic contaminants, being minimal the differences between organically and conventionally produced meats. The pattern of meat consumption exceeded the maximum limits, being, according to the levels of contaminants associated with a relevant carcinogenic risk. The consumption of organically produced meat did not reduce this carcinogenic risk. It was even higher in the case of lamb consumption (Rodriguez-Hernandez et al., 2015b).

Recently, Kim (2012) reviewed the origins, occurrence, transfer through the food chain, and the significance for human health of a number of contaminants and residues (PCDD/Fs, PCBs, PBDEs, PFOS and perfluorooctanoic acid (PFOA), pesticides, toxic metals, and veterinary drugs) in red meat. In agreement with the results of our case-study (Catalonia, Spain), it was concluded that prevention and reduction of the release of chemical contaminants into the environment were important steps to reduce the levels of these pollutants in red meats, and consequently, to reduce the health risks for the consumers (Kim, 2012).

In recent years, we have extensively reviewed the available scientific literature concerning human daily dietary exposure to the following environmental contaminants: PCDD/Fs (Bocio and Domingo, 2005; Domingo and Bocio, 2007), PCBs (Domingo, and Bocio, 2007), PBDEs (Domingo, 2004a, 2012a; Domingo et al., 2008), PCNs (Domingo, 2004b), PCDEs (Domingo, 2006), PFASs (Domingo, 2012b) and PAHs (Domingo and Nadal, 2015). Meat and meat products were in all the reviews. Taking together the information summarized in these papers, as well the experimental data obtained in our case-study (Catalonia, Spain), in general terms, it can be stated that this food group is not the main responsible of the daily dietary exposure to carcinogenic, or probably carcinogenic, environmental pollutants such as As, Cd and Pb, PCDD/Fs (2,3,7,8-TCDD, which is classified into the Group 1), various DL-PCBs, benzo[a]pyrene and other PAHs, or hexachlorobenzene (probable human carcinogen group B2, US EPA). On the other hand, it has not been established yet whether PCNs, PCDEs, PBDEs, or PFAAs such as PFOS, can cause cancer in humans. Anyhow, the group of meat and meat products does not occupy for most of these contaminants, the first place among the different food groups with respect to its contribution to the dietary exposure to these environmental pollutants. Fish and shellfish is usually in the first position (Domingo, 2015).

5. Influence of cooking on the levels of environmental pollutants in meat and meat products

The potential toxicants in foods, including meat and meat products, are derived from natural or industrial sources. In addition to natural toxins and toxins present in animals for human consumption, another group of potentially toxic compounds in food are environmental pollutants, while a third group are those organic chemicals produced when food is cooked and/or processed, and include mainly PAHs, HAAs and NOCs

(Engel et al., 2015; Peshin et al., 2002). In 2008, we initiated in our laboratory a study aimed at evaluating the effects of traditional cooking processes in Catalonia (fried, grilled, roast and boiled) on the concentrations of various inorganic and organic environmental pollutants in a number of foods. Veal steak, loin of pork, breast and thigh of chicken, and steak and rib of lamb, were selected as meat samples (Perelló et al., 2008, 2009, 2010). The levels of As, Cd, Hg, Pb, PCDD/Fs, PCBs, PCDEs, PBDEs, 16 PAHs and HCB were determined in raw and cooked samples. In general terms, the cooking process influenced only very slightly the content of toxic metals in food, while cooking reduced PCDD/F levels in veal and pork samples. (Perelló et al., 2008). In contrast to PCDD/Fs, all cooking processes (excepting grilled chicken) enhanced PCB concentrations and those of the ∑PCDEs (excepting roasting for chicken) (Perelló et al., 2010). We also determined the levels of 11 PFASs in composite samples of veal steak (raw, grilled, and fried), pork loin (raw, grilled, and fried), chicken breast (raw, grilled, and fried), black pudding (uncooked), liver lamb (raw), pate of pork liver, foie gras of duck, hot dogs and chicken nuggets (fried). PFOS was the compound most frequently detected, being found in grilled pork, grilled and fried chicken, and lamb liver, while perfluorohexanoic acid (PFHxA) was detected in samples of raw veal, chicken nuggets and hot dogs. The results were not sufficiently clear to establish if cooking with non-stick cookware could contribute to a higher human exposure to PFASs (Ericson-Jogsten et al., 2009).

According to these results, as well as other data from the scientific literature recently reviewed by Domingo (2011), it was concluded that although certain cooking processes could reduce (or increase) the levels of chemical contaminants in food, it seems that the influence of cooking on the concentration of these environmental pollutants depends not only on the particular cooking process, but even more on the contents of the contaminants in specific food item before being cooked. In general terms, cooking procedures that release or remove fat from the product should tend to reduce the total concentrations of the organic contaminants in the cooked food. This might be of special relevance in the current context on the carcinogenicity of consumption of meat and meat products, at least, with respect to the most widespread environmental pollutants.

The influence of cooking on the presence of NOCs and HAAs in meats was not included in the present review. However, because of the potential carcinogenicity of these undesirable compounds when consuming cooked meats, we would like to highlight some recent reviews on that important issue (Kim et al., 2013; Abid et al., 2014; Behsnilian et al., 2014; Trafialek and Kolanowski, 2014). In turn, the human dietary exposure to PAHs (including meat and meat products) was recently reviewed by Domingo and Nadal (2015).

6. Conclusions

Because of the great socioeconomic consequences of the recent decision of the IARC (2015) on the carcinogenicity of consumption of red and processed meat, the main goal of the present article was adding information on that relevant issue. The press release of the IARC has raised a considerable concern, not only in the consumers, but also in the meat and related industries, as well as in multiple businesses related to the consumption of meat and meat products. Logically, we quite agree with the IARC on its classification of consumption of red meat and processed meat in the Groups 2A and 1, respectively, as this classification is based on an important number of scientific studies supporting the statements (Bouvard et al., 2015). However, and according to the information reviewed in our current article, we would like to add some conclusions that we feel may be useful for establishing the specific risks for the consumers.

The IARC have noted that meat processing such as curing and smoking, could result in formation of the carcinogenic chemicals NOCs and PAHs, while cooking could also produce HAAs and PAHs. However, and based on the information contained in the report by Bouvard et al. (2015), the IARC did not consider the influence of environmental pollutants on the carcinogenicity of consumption of meats, which may be already found in the own raw/unprocessed meat. This would be the case of, at least, As, Cd, Pb, PCDD/Fs, DL-PCBs, and some other PAHs. The results of our studies on that subject, together with those of other researchers over the world, suggest that although certain cooking processes could modify (either reducing or increasing) the levels of chemical contaminants in food, it seems that the influence of cooking on the concentrations of these contaminants depends not only on the particular cooking process, but even more on their original contents in each specific food item. As most of these environmental pollutants are organic, cooking procedures that release or remove fat from the meat should tend to reduce the total concentrations of these contaminants in the cooked meat (Domingo, 2011; Perelló et al., 2009, 2010). Anyhow, we have noted that, in general terms, chicken contains less organic contaminants than red meats. Once again, and as with most foods, to reduce the daily intake of fats through the consumption of meat and meat products will be useful for a healthy diet. This reduction may prevent cardiovascular risks and also a part of the carcinogenic risks, at least those derived from dietary exposure to certain carcinogenic environmental contaminants. On the other hand, in order to calm down the consumers, we miss more information on the generation of NOCs and HAAs in the different processes in which meats are involved and their prevention. Some tool that allows balancing the health benefits and risks of a regular consumption of meat and meat products could be very useful for the general population. In relation to this, an interesting precedent is related with the regular fish and other seafood consumption. Thus, it was concluded that although a regular consumption of most fish and shellfish species should not mean adverse health effects for the consumers, the specific fish and shellfish species consumed, the frequency of consumption, as well as the meal size, are essential issues for adequately balancing the health benefits and risks of regular fish consumption (Domingo, 2015). This could be also valid for meat and meat products.

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